BIOLOGY

Text II *Life and living processes*

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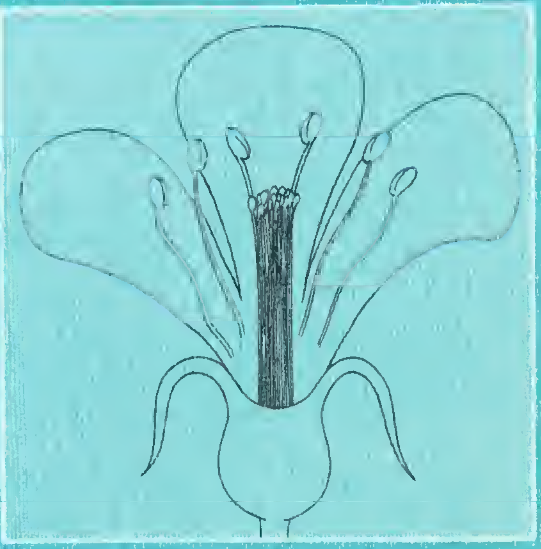

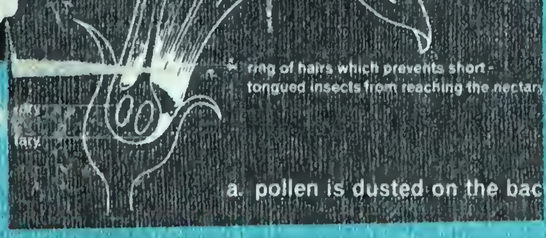
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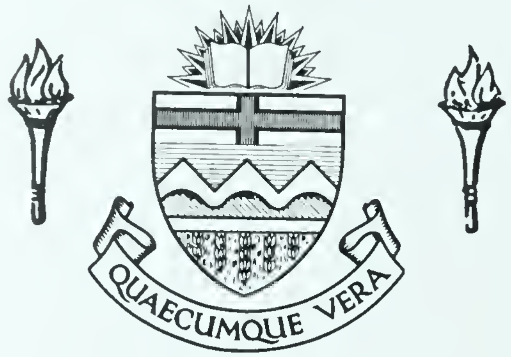

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Nuffield Biology Text II

Life and living processes

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Life and living processes

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Foreword

This volume is one of the first to be produced by the Nuffield Science Teaching Project, whose work began early in 1962. At that time many individual schoolteachers and a number of organizations in Britain (among whom the Scottish Education Department and the Association for Science Education, as it now is, were conspicuous) had drawn attention to the need for a renewal of the science curriculum and for a wider study of imaginative ways of teaching scientific subjects. The trustees of the Nuffield Foundation considered that there were great opportunities here. They therefore set up a science teaching project and allocated large resources to its work.

The first problems to be tackled were concerned with the teaching of O-Level physics, chemistry, and biology in secondary schools. The programme has since been extended to the teaching of science in sixth forms, in primary schools, and in secondary school classes which are not studying for O-Level examinations. In all these programmes the principal aim is to develop materials that will help teachers to present science in a lively, exciting, and intelligible way. Since the work has been done by teachers, this volume and its companions belong to the teaching profession as a whole.

The production of the materials would not have been possible without the wholehearted and unstinting collaboration of the team members (mostly teachers on secondment from schools); the consultative committees who helped to give the work direction and purpose; the teachers in the 170 schools who participated in the trials of these and other materials; the headmasters, local authorities, and boards of governors who agreed that their schools should accept extra burdens in order to further the work of the project; and the many other people and organizations that have contributed good advice, practical assistance, or generous gifts of material and money.

To the extent that this initiative in curriculum development is already the common property of the science teaching profession, it is important that the current volumes should be thought of as contributions to a continuing process. The revision and renewal which will be necessary in the future, will be greatly helped by the interest and the comments of those who use the full Nuffield programme and of those who follow only some of its suggestions. By their interest in the project, the trustees of the Nuffield Foundation have sought to demonstrate that the continuing renewal of the curriculum – in all subjects – should be a major educational objective.

Brian Young
Director of the Nuffield Foundation

866927

Text: Year II

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Preface

To the pupil

You have probably been told that Biology is the study of living things. This is true but, by itself, the statement does not tell you what Biology is really about. In this course we want to do more than just teach you how living things function; we want you to understand why scientists wish to know about life and how they set about finding out biological truths.

Scientists must be curious; they must be prepared to form tentative guessing answers to the questions they ask themselves; and they must be able to test these guesses. We have tried to guide you through this process, to show you why you should be curious, what kinds of questions you should investigate, and how you should devise and carry out experiments. Experiments are not intended to prove things you already know; they are to investigate whether something does or does not happen so that you can form hypotheses which, themselves, can be tested by further experiments. Thus, a negative result may be as important as a positive one. We have also tried to indicate how you should use the results you get; how you should test them further and how you should relate them to the questions you posed yourselves.

By the end of this course we hope you will know not only more about living things, particularly man, but also more about how to study living things both in the laboratory and in their natural state.

To the teacher

The essence of this Nuffield course in biology is 'science for all'. In devising it, our intention has been to provide a balanced and up-to-date view of the subject suitable for pupils who will leave school at the age of sixteen and do no more formal biology. For some it will also provide a jumping-off point for further study at A-Level.

The course has been built around a number of fundamental themes. Such issues as the relationship of structure and function, adaptation, and the interaction of organism and environment recur again and again in different contexts throughout the five-year period. The course is designed to foster a critical approach to the subject with an emphasis on experimentation and enquiry rather than on the mere assimilation of facts. In terms of a conventional syllabus this means that less factual matter is included. This in itself is no bad thing, provided the principles of the new teaching are accepted and the methods used are in sympathy with the aims of the course. In order to foster this outlook, a Teachers' Guide has been produced. This is closely cross-referenced to the Text and contains copious notes on teaching methods, also much technical matter relating to practical work, including additional experiments. In short, our aim has been to produce not only a new syllabus, but, more important, a new *approach to teaching.*

The course falls clearly into two parts: the first two years, which can be regarded as introductory, and the remaining three, which constitute the next (intermediate) phase. The introductory phase is characterized by a broad general approach to the subject. In the intermediate phase the treatment becomes more quantitative with greater emphasis on experimentation and reasoning.

At the end of most chapters of the text there is a short section entitled 'Background reading'. The topics covered relate to the preceding chapter in a variety of ways and are usually extensions of particular subjects which it has not been possible to develop fully elsewhere. This material is intended for out-of-school reading and it will not be examined in G.C.E.

In addition to the texts and guides we have produced a number of 8 mm Film Loops for use with projectors such as the Technicolor 800 E. These are referred to at appropriate points in the guide and form an integral part of the course. They are obtainable through the same sources as the books.

Chapter 1

Man and microbes: the discovery of small organisms

1.1 The use of a hand lens

In this chapter we shall be investigating small organisms. Some of them are so small that you will need a lens to magnify them sufficiently to be able to see them at all.

The hand lenses used in biology laboratories usually magnify an object either five or eight times. Since you will be using a hand lens frequently, it is important that you should understand how to use it in the correct way.

1. Pull a hair out of your head and lay it across a small piece of Sellotape. You can probably see it quite clearly. Can you decide which is the root end originally attached to your head?
2. Now hold a lens about three inches from your eye and bring the Sellotape slowly up to the lens until the hair is in focus. Can you make out the root of the hair much more clearly? Does the hair appear to be much thicker

What you have done is to hold the lens still and bring the object *up to the lens* until it is in focus.

One of the difficulties about using lenses to magnify things is that when we increase the magnification we have to bring the lens very close to the object we are looking at, in order to get it into focus. But this means that the lens and the object must be positioned very accurately in relation to each other, so that the object does not bob in and out of focus.

Scientists in the seventeenth century, who experimented with some of the earliest magnifying glasses, soon found these difficulties for themselves and set about trying to find a way to overcome them.

1.11 The first microscope

One of these early experimenters was a Dutchman called Anton van Leeuwenhoek (1632–1723) whose portrait you can see in figure 1. He had the bright idea of mounting a high powered lens (only $\frac{1}{8}$ inch across) in a metal plate instead of holding it in his hand. The object to be examined was mounted on the pointed rod

Figure 1
Portrait of Anton van Leeuwenhoek (1632–1723). He is holding a lens in his hand.
Photo, Wellcome Historical Museum.

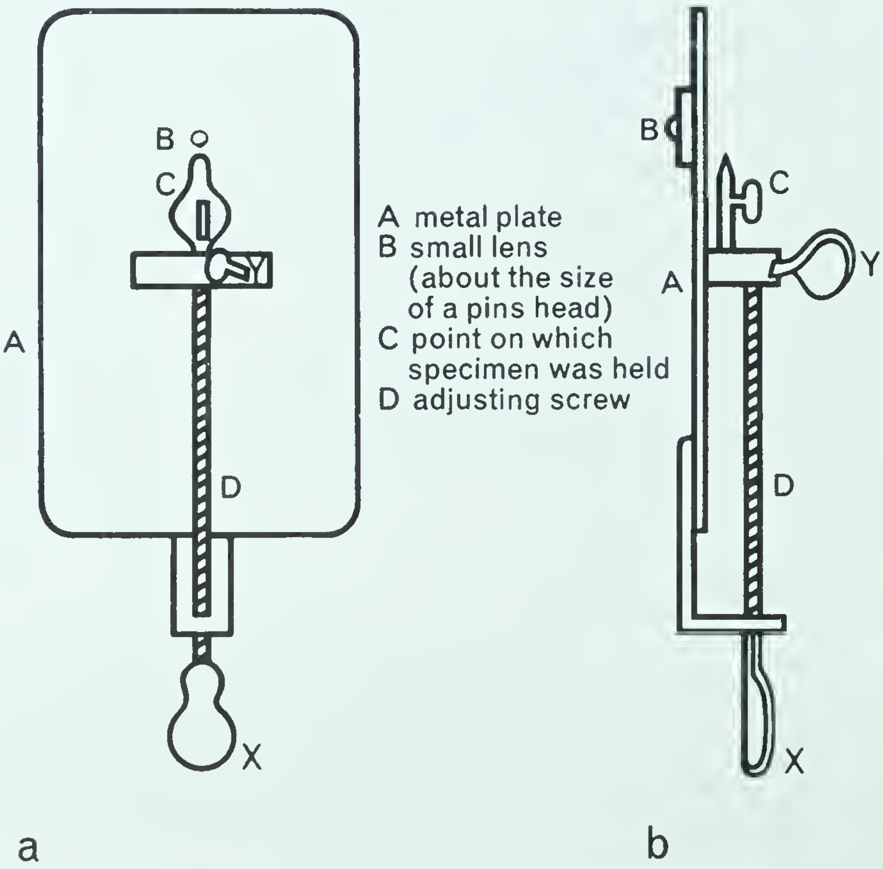

B
C
A
D
X
Y
A metal plate
B small lens (about the size of a pins head)
C point on which specimen was held
D adjusting screw
B
C
Y
A
D
X
a
b

Figure 2
Anton van Leeuwenhoek's simple microscope. These are drawings to show how the microscope worked. (*a*) shows the microscope in face view and (*b*) in side view. Notice the very small lens and the point on which the specimen was held. The point could be raised or lowered by the screw X and brought nearer or further away from the lens by means of the screw Y.

which could be moved up or down, and nearer or further away from the lens, by means of two screws. This arrangement overcame the problem of movement of the object. Figure 2 is a diagram of Leeuwenhoek's simple microscope.

Leeuwenhoek's hobby was making lenses and during his lifetime he constructed more than 240 of these rather crude little microscopes. The amount of magnification he obtained by using one was about × 240, which is a great deal better than anything we can achieve with a hand lens today. Figure 3 shows a copy of Leeuwenhoek's original microscope.

By modern standards these early microscopes were poor. The picture they produced was not very clear and the magnification was quite low. An ordinary school microscope will magnify objects 400 times without difficulty, while good instruments have magnifications of × 1,000, or even more. But in spite of these difficulties, Leeuwenhoek was able to see in such things as soil or souring milk a whole new world of tiny living creatures which no one before him had dreamed of. He called his minute creatures 'little animals'. Today we call them microbes.

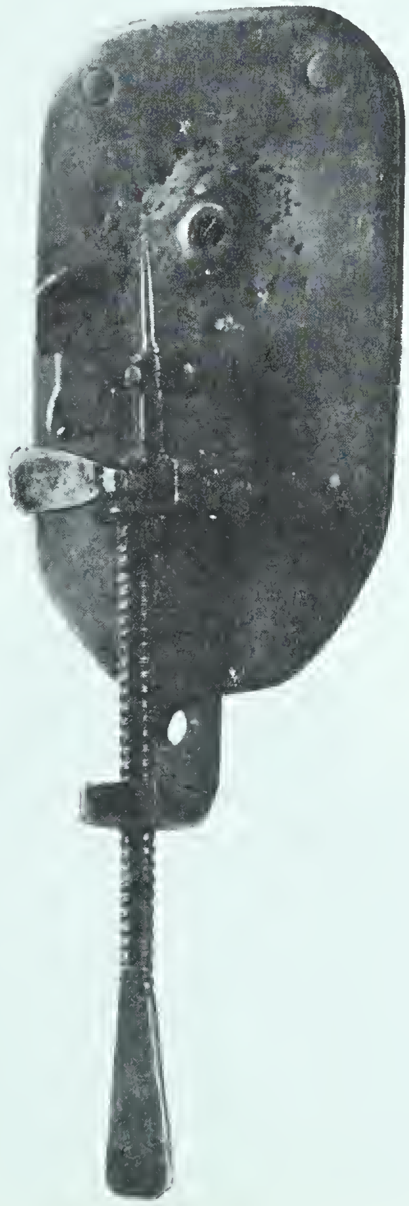


Figure 3
A facsimile of Leeuwenhoek's original microscope in the University of Utrecht. *Photo, Wellcome Historical Museum.*

1.12 Where do microbes come from?

Leeuwenhoek carried out many different kinds of biological experiments, but in spite of his efforts he never got much further towards finding out what his 'little animals' really were or where they came from. Six years after his death an Italian, called Lazaro Spallanzani, was born. You can see his portrait in figure 4. Spallanzani was to become a famous scientist and, as we shall see, his experiments served to continue the study of microbes more or less from the point where Leeuwenhoek left off.

In the eighteenth century people still thought that Leeuwenhoek's 'little animals' appeared mysteriously from materials such as mud which are not alive. This idea is known as the 'theory of spontaneous generation' – suggesting that living things could suddenly be formed from non-living. In many ways Spallanzani's views were far in advance of his time, for he set about devising experiments to find out whether microbes could, in fact, 'appear' in substances which previously contained no microbes. For instance, in one of his famous experiments he arranged nineteen flasks containing various different liquids prepared with water from such things as maize and barley grains, and also eggs. Having poured the liquids into the flasks he sealed the tops so that no air could enter. Spallanzani then immersed them for an hour in boiling water, his idea being to kill any living things that might be inside. He then let them cool and left them unopened for several days. On opening them he found no microbes at all.

You must remember that in Spallanzani's time, experimentation

Figure 4
Lazaro Spallanzani (1729–99). He was an Italian whose experimental methods in biology and physics were far in advance of his time. *Photo, Wellcome Historical Museum.*

of this kind was something quite new in science. Previously people had been content to record and draw conclusions only from what they could observe under natural conditions. The idea of setting up a hypothesis and then designing an experiment to test it was only just beginning to dawn. So it is not surprising that, judged by what we know today, Spallanzani's experiment was incomplete. If you had been doing the same experiment today, could you think of anything he left out that you would have included?

From the results of these experiments, Spallanzani argued that spontaneous generation could not possibly occur. Whether we agree with his claim or not, the fact remains that his new approach greatly helped men like Pasteur who came after him. Let us not forget, too, the debt that Spallanzani owed to Leeuwenhoek, for he could never have detected the microbes which he found in his various nourishing liquids without a microscope.

1.13 What are microbes?

Beyond the fact that they are very small, what exactly do we mean by 'microbes'? Nowadays the word 'microbes' is the name given to a group of organisms which includes such things as some of the tiny fungi, the one-celled animals called *Protozoa*, the very small bacteria and even smaller viruses which need magnifications of up to × 100,000 in order for them to be seen.

Although most of these small organisms cannot be seen with the naked eye or even under the low power of the microscope (at a magnification of about × 200), we can find out quite a lot about them for ourselves; how they spread, what effects they have on animals and plants and even upon ourselves. Some of these effects are bad, for many bacteria, viruses, and fungi can cause disease of one kind or another – whooping cough, measles, and ringworm for example.

But by no means all microbes are harmful. Certain kinds, which we shall be learning about, are helpful in preventing diseases, in the preservation of food, and in the making of such things as cheese, wine, and bread.

1.14 Microbes useful to man – yeast

One of the useful microbes is the fungus yeast which we use in making bread. We can buy living yeast from a baker's shop. In large quantities it feels rather like a lump of soft putty. What does yeast look like when it is greatly magnified?

Looking at yeast under the microscope

Examine a very small quantity of yeast under a microscope. Can you distinguish the separate round cells sometimes sticking together in pairs? They will not appear to be as large as the yeast cells in figure 5, because under the ordinary high power of a microscope they have only been magnified about 400 times.

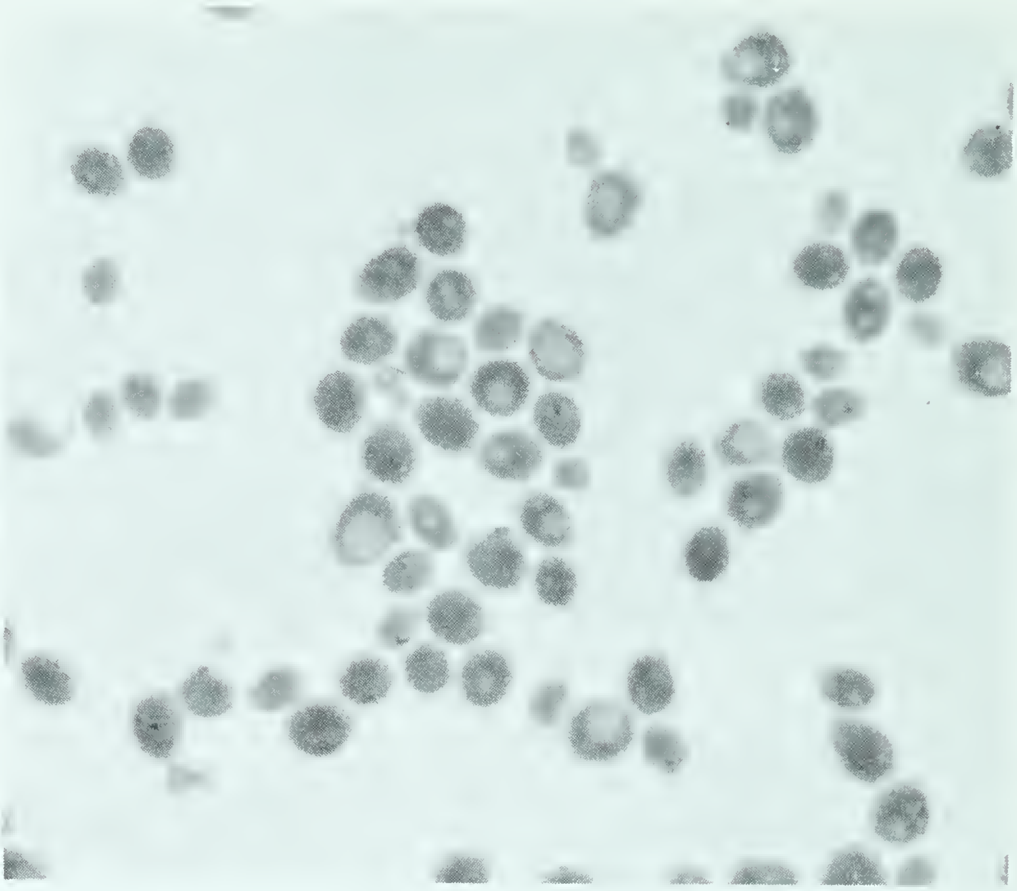


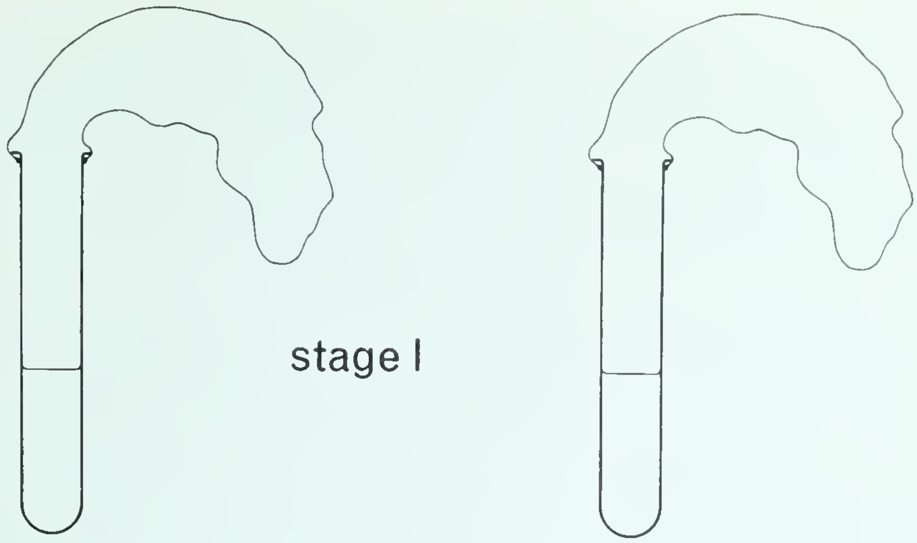
Figure 5
Photomicrograph of yeast cells × 600 (approx.). Yeast cells are often to be found in pairs. They are much larger than bacteria.
Photo, Flatters & Garnett.

1.15 What happens when yeast and sugar are mixed together and warmed?

You are provided with two test-tubes A and B each containing the same amount of yeast and sugar solution.

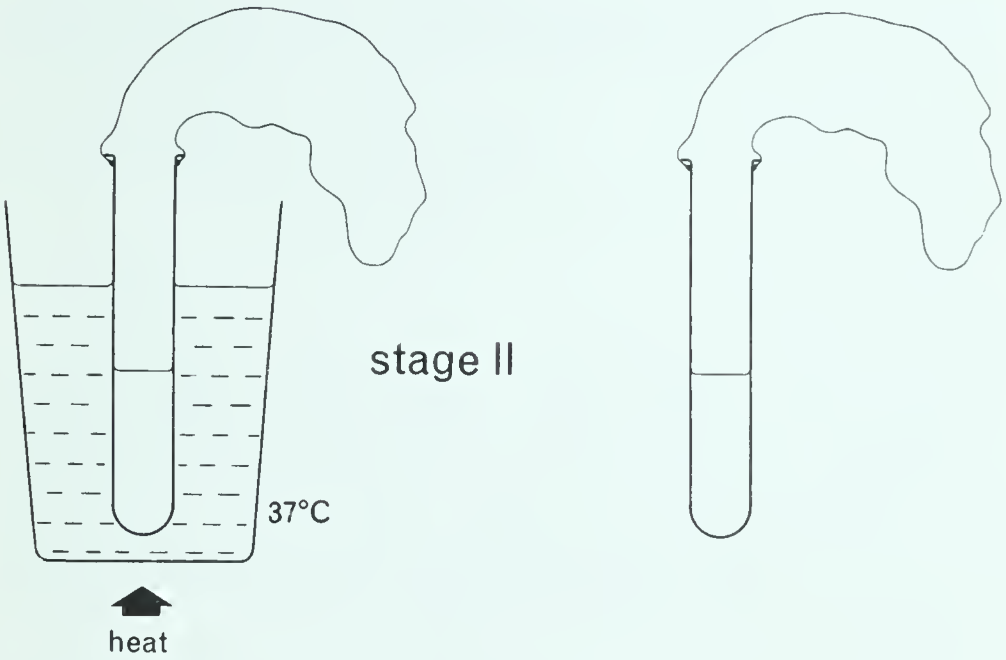
1. Over each of the test-tubes place a balloon as in figure 6, stage I.
2. Take the temperature of the air in the room where you are working. At room temperature, is the solution in either of the test-tubes bubbling? Is either of the balloons inflated at all? If so, would you say that the solution is making a gas?
3. Place tube A in a water bath at 37°C, which is just above the temperature of our own bodies. In this way you could tell if you get a different result by raising the temperature of the solution. (See figure 6, stage II.)
4. After fifteen minutes record your results. What has happened to the balloons on A and B?
5. You are provided with test-tube C which contains yeast solution but no sugar, and test-tube D which contains sugar solution but no yeast. Place C and D in the water bath at 37°C. (See figure 6, stage III.)
6. After fifteen minutes record your results. What has happened to the balloons on C and D?

In the first part of the experiment (see figure 6, stages I and II) you may have found that at room temperature there was a slight bubbling of the yeast and sugar solution in A and B, but that by placing A in a water bath at 37°C the bubbling increased and the balloon inflated indicating that a gas was given off. Tube B, kept



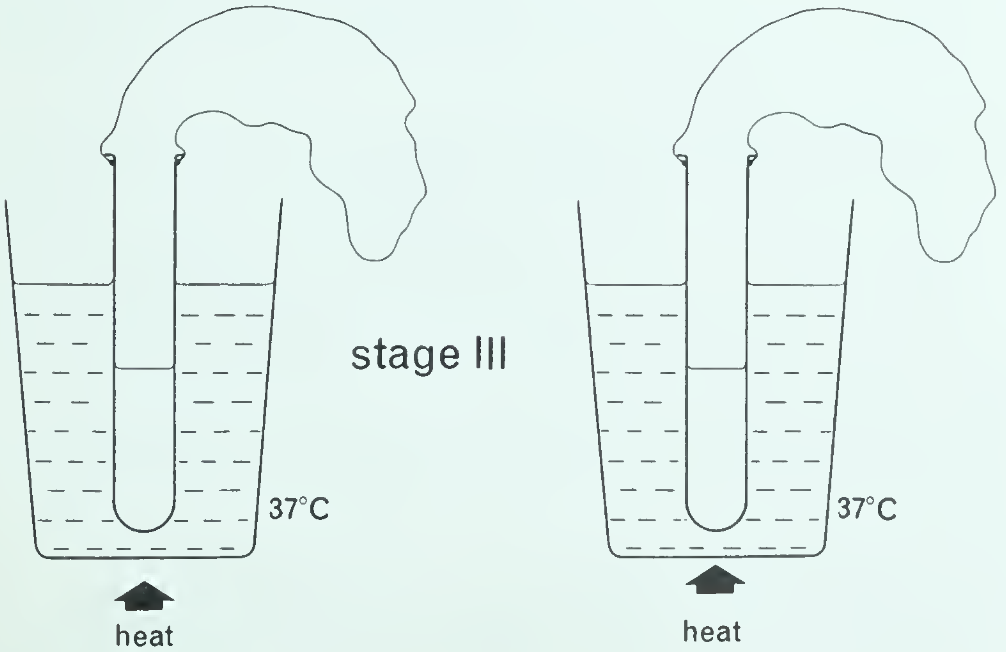
A. sugar solution + yeast

B. sugar solution + yeast



A. sugar solution + yeast

B. sugar solution + yeast



C. yeast solution only

D. sugar solution only

Figure 6
What happens when yeast and sugar are mixed together and warmed?

at room temperature, showed what happened at a lower temperature. Would you say that B acted as a control in this experiment?

The next part of the experiment (see figure 6, stage III) is to find out if any gas at all is given off by heating yeast solution alone or sugar solution alone. Would you say that C and D acted as controls for A and B? What did these tubes show?

Controls are an essential part of any experiment, even if they only show that something has *not* happened. By leaving out sugar from tube C and yeast from tube D we may get no result with the balloon. If so, we shall have proved, by our last experiment, that both yeast and sugar are necessary for a gas to be given off.

Having performed these experiments with yeast, turn back to section 1.12 and read it again. If you have not spotted it already, can you now see where the design of Spallanzani's experiment went wrong?

You will remember that, by boiling all the flasks containing liquids and then sealing them, Spallanzani treated them in the same way. A proper control for this experiment would have been to leave unboiled an equal number of flasks containing the same liquids and to seal them. If Spallanzani had found microbes in these control flasks what would this have proved?

1.16 Making bread

Yeast lives in places where a supply of sugar is available. For instance it forms the fine, powdery 'bloom' on the outside of plums and grapes. Normally the gas formed by the fungus escapes into the atmosphere and is lost, but for many centuries man has made use of it in making bread. Here is a case in which a biological process has proved to be a great benefit to mankind. We shall come across other examples in later chapters.

We have already learned that bread is made with yeast (see section 1.14), and you have probably heard the expression used by bakers that yeast 'raises' the dough that makes bread. In fact, after the dough is made, bakers set it aside in a warm place, to 'prove' (or rise) before it is baked.

The balloons of the two control tubes C and D in the experiment in section 1.15 did not inflate, which showed that yeast alone or sugar alone did not give off a gas. But if they are heated together in solution a gas is given off as was shown by the inflation of the balloon on tube A. Has this got anything to do with the reason why we use yeast in making bread? We could make some dough to find out.

1. Use the same proportions of flour, sugar, yeast, and water, as a baker, which is:
150 g plain flour.
2 g yeast (dried yeast is best).
4 g sugar, 100 cm³ water, warmed to about 32°C.
2. Mix the sugar with the flour in a bowl and then mix in the yeast.

3. Make a well in the centre of the flour and add the warmed water.
4. Stir the water into the flour, sugar, and yeast mixture and then knead into a dough.
5. Divide the lump of dough into three equal parts, putting each into a separate 1 lb jam jar or large evaporating basin.
6. Label the jars A, B, and C, mark the height of the dough in each container, and cover them with a cloth.
7. Leave A in a warm place such as over hot pipes, B in a cool place, and C in a refrigerator.
8. After about thirty minutes examine the jars. Has the dough risen?

What control experiment can you suggest to prove that it is the yeast which causes the dough to rise? Can you see any connection between this experiment and the previous one (see section 1.14) in which a gas is given off when yeast and sugar are warmed in solution? From your results would you say that temperature has any effect on the amount the dough has risen in A, B, and C?

1.17 Making your own wine

There are many activities besides baking, in which yeast is important. For instance it is used in the brewing of beer and in the making of various wines from fruit juices and from plants such as dandelions. Most kinds of fruit, but particularly grapes, have yeast cells growing on their skins. So, when grapes are crushed to make wine, the yeast from their skins acts on the sugar they contain to make alcohol.

You can try making your own wine from apple juice (the kind you buy in bottles from the grocer) and yeast.

1. Sprinkle a few grains of dried yeast into a test-tube of apple juice.
2. Place the tube, plugged with cottonwool, in an incubator at 25°C, or keep it in a warm place.
3. Incubate a second test-tube of apple juice without yeast as a control.
4. After a few days remove the cottonwool plugs, smell and taste the apple juice in both tubes. What difference do you notice?

1.2 Bacteria

Leeuwenhoek's 'little animals', as we have seen, must have been a collection of all sorts of small creatures (micro-organisms) most of which were, in fact, plants. However, the difference between a plant and an animal need not worry us now. It is a subject that you might like to think about and discuss.

We have already come across one kind of micro-organism – the fungus, yeast. No doubt this was one of the microbes that Leeuwenhoek saw under his microscope. Another very important group of microbes are the *bacteria* which, like yeast, are also minute plants. There are many different kinds of bacteria and they can be found almost everywhere in the world, in all sorts of places. They occur most abundantly where there is suitable food, moisture, and the right temperature for growth. Being small they are easily spread from one place to another by air currents, water, and by other living creatures, which carry them in or on their bodies. Indeed people are now worried lest space travel might carry 'foreign' bacteria to the planets or from the planets back to earth.

Not all bacteria are harmful, although that is a popular belief. It is true that some kinds of bacteria can cause diseases such as diphtheria, typhoid, and pneumonia. Yet without bacteria, many processes upon which we depend could not take place. For instance, bacteria of many kinds are needed in the soil to help bring about the decay of dead plants and animals.

1.21 Sizes and shapes of bacteria

Bacteria, as we now realize, are very small organisms, but just how small it is difficult to understand. The crude microscope made by Leeuwenhoek, which magnified about 240 times, was only sufficiently powerful to see the largest bacteria. The best modern optical microscopes magnify more than 1,000 times, and if a bacterium of an average size were magnified × 1,000, it would appear as big as a full stop on this page of print.

To make these very small sizes seem more real a new measure of length, the micron, is used. One micron is equal to one thousandth of a millimetre and is written as the Greek letter μ. Bacteria vary in size from 0·2 μ to 2·0 μ, the average size being about 1 μ. The head of an ordinary pin measures about 2 millimetres across, thus 2,000 averaged sized bacteria, placed side by side, would just fit in across a pin head.

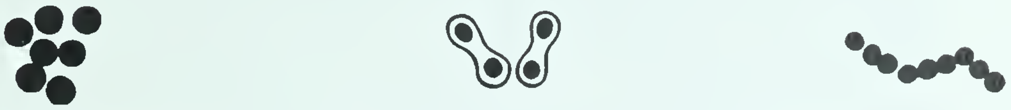
The striking thing about bacteria from the point of view of their structure, is that they vary so little. We can divide them quite simply into three groups (see figure 7).

a. Spheres (*cocci*). These range in size from 0·2 μ to 1·5 μ and are very common. Many are harmless, particularly most of those occurring in soil. Others cause human disease such as sore throats (*Streptococcus*).

b. Rods (*bacilli*). These are cylindrical in shape and are larger than *cocci* (1·2 μ to 2·5 μ). Most of those in the soil are harmless. Some of these (*Bacillus megaterium*) are among the largest bacteria known, being about 2·8 μ long (see figure 8). The scale of 5 μ is given on the photograph to show its size. A few cause disease in man, as for instance *Shigella* which causes a form of dysentery.

c. Spiral or comma-shaped (*spirilla*). These are rarer than the other two groups and their size is roughly intermediate (1·5 μ). Many are harmless, but a few cause disease in man, e.g. cholera.

a. *Cocci* These are round, sometimes in groups, sometimes in chains

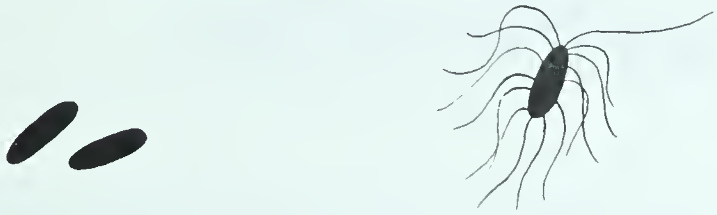


A group of *Cocci*

Diplococci
(two cells together)
eg *Diplococcus pneumoniae*

Streptococci
(chain of cells)
eg *Streptococcus lactis*

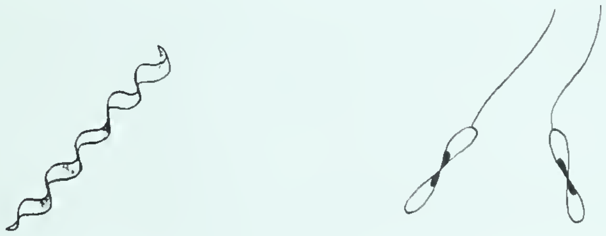
b. *Bacilli* These are rod-shaped, sometimes with round ends, sometimes with square ends. Some bacilli have long flagellæ (tails)



Single round ended-rods
eg *Escherichia coli*

Flagellate rod
eg *Salmonella typhi*

c. *Spirilla* These are spiral or comma-shaped



eg *Spirillum*

Comma-shaped with
single flagellum
eg *Vibrio cholerae*

Figure 7
Different kinds of bacteria. The smallest bacteria are 0·2 μ and the largest 2·8 μ. Even within a single group their sizes vary greatly.

It is worth adding that when conditions are not suitable for them to feed and grow, many bacteria form *spores*. These are resting stages when normal life almost comes to a stop. Spores can survive in conditions which would kill most things. Some can survive boiling water and even liquid air at a temperature as low as −195°C. Being very light they can be blown about in air currents. This is one of the ways in which bacteria have managed to spread to all parts of the earth's surface.

1.22 Micro-organisms in the soil

If bacteria like living on rotting things as Spallanzani discovered, there ought to be large numbers in soil where there are the dead remains of plants and animals for them to feed upon. What evidence is there that they really do occur in soil; and, if they occur, how common are they? As we have seen, bacteria are very small. How then are we to get them out of the soil if we cannot see them?

We could try to collect bacteria simply by shaking a little fresh soil up with distilled water, and then transferring the liquid with

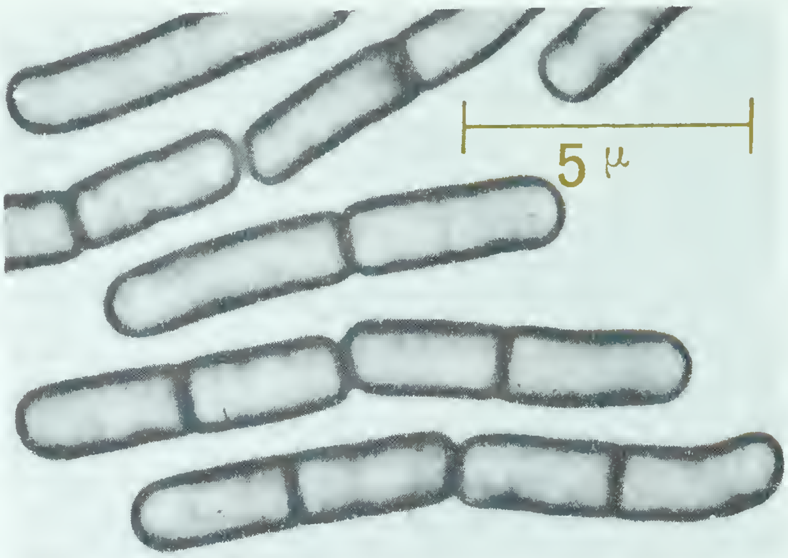


Figure 8
Bacillus megaterium. This is one of the largest bacteria. Each cell is 2·8 μ long and 1·2 μ thick. It is to be found in soil.
From Hawker, An Introduction to the Biology of Micro-organisms *published by Edward Arnold.*

Figure 9
Louis Pasteur (1822–95). *Photograph of a print in the National Portrait Gallery Reference Library.*

any bacteria it may contain to conditions in which bacteria can grow. Spallanzani used to use liquids such as broths to grow his bacteria. Today, we use a jelly called agar to which have been added certain things that bacteria need for food. The substance is then known as nutrient agar.

You are provided with some water in a flask which has been made by shaking up soil in distilled water. You are also provided with a tube of agar.

1. Using a 1 cm^3 pipette or 2 cm^3 syringe, draw up 1 cm^3 of soil from the flask and empty it into a Petri dish.
2. Pour the agar from the tube onto the soil water in the Petri dish.
3. Replace the lid and rotate the dish very carefully to mix the agar with the soil water. As the agar cools it will set to a jelly.
4. Put the dish and its contents into an incubator at 37 °C.
5. After two days remove it from the incubator and examine the agar. Have a look particularly for any creamy-white circles or small dots. These are colonies of bacteria. If you find some colonies, scrape off a very little with a mounted needle into a drop of water on a microscope slide. What can you see under a microscope?

It has been calculated that if we could skim off the top six inches of earth from an acre of good soil, there would be about 1,500 lb of bacteria of different kinds. Put in another way, there would be 2,500 million bacteria in each gram of soil. A saltspoonful of dry garden soil weighs about $1\frac{1}{2}$ g. It would also contain about twice as many bacteria as there are men, women, and children in the whole world.

1.3 Micro-organisms in the air

Spallanzani's experiments showed that if liquids in which bacteria normally lived were boiled in flasks, sealed from the air and left for many days, no microbes were found in them. From this he concluded that these tiny living things could not be formed from something which was not living. Spontaneous generation did not occur. However, few people believed him. No doubt there were several reasons for this; for instance we saw that Spallanzani used no proper controls. One failing of his experiments was that, after boiling, he kept the flasks closed. It could be argued that something had happened to the air inside the flask which prevented more microbes from growing.

It was not until 1861, nearly a hundred years later, that the famous French scientist Louis Pasteur carried out a series of experiments to find out if bacteria could be formed from dead material in the presence of air. Figure 9 shows a portrait of Pasteur. Pasteur must have reasoned something like this. We know that bacteria are small and light, but the fact that they are found all over the face of the earth shows that they settle out of the air – that is, they must be slightly heavier than air. If air were to be sucked very slowly through a tube which was not straight but bent into a series of curves, any dust or bacteria present should settle in the bottom of the curves and the remaining air should be quite pure.

With this idea in mind, Pasteur used a special flask with a neck drawn out into a fine tube. A nutrient broth similar to that which you used in your culture of soil bacteria was poured down the neck of the flask, which was then bent into an S-shaped curve over a flame (see figure 10). These flasks are known today as Pasteur's flasks. The broth was then allowed to cool slowly. Pasteur prepared a number of flasks in this way. He left them for several months before he examined them again. But when he did, he found the broth still unchanged and no microbes present. In Pasteur's own words, 'It is a remarkable thing, likely to astonish everybody used to the delicacy of experiments relating to so-called "spontaneous generation", that the liquid in such a flask will remain indefinitely unchanged'.

Pasteur said that bacteria were present everywhere in the air. His flasks were open to the air. How was it, then, that the broth did not become infected with microbes from the air?

As you may know, when warm air cools, its volume gets less. This is what happened in Pasteur's flasks; as they cooled down, so more air came in very slowly from the outside down the swan necks, and into the flasks. Here was the secret of his success. He had not shut out the air; it was free to pass in and out of the flasks, but slowly enough for the dust particles and microbes to be left in the

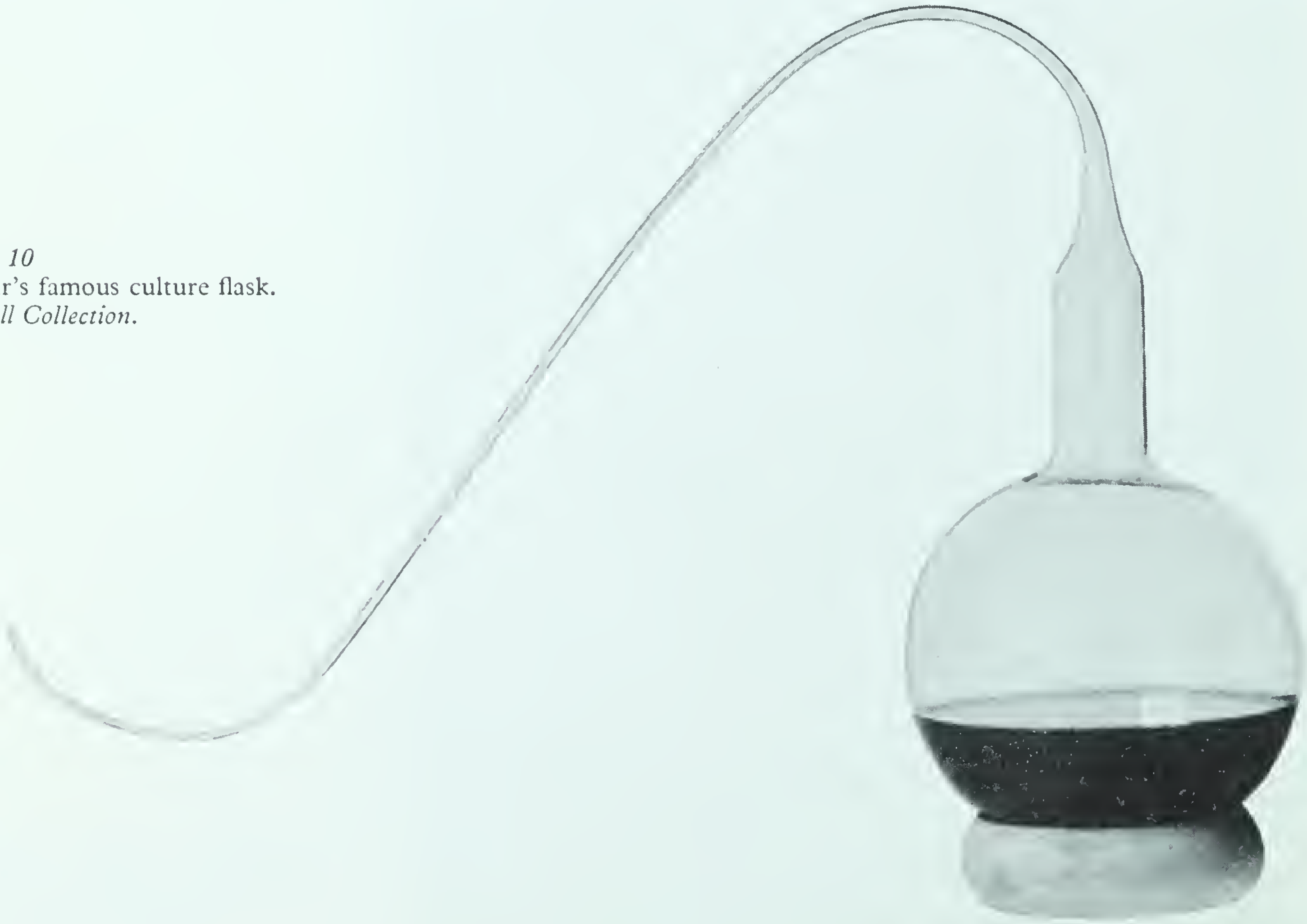
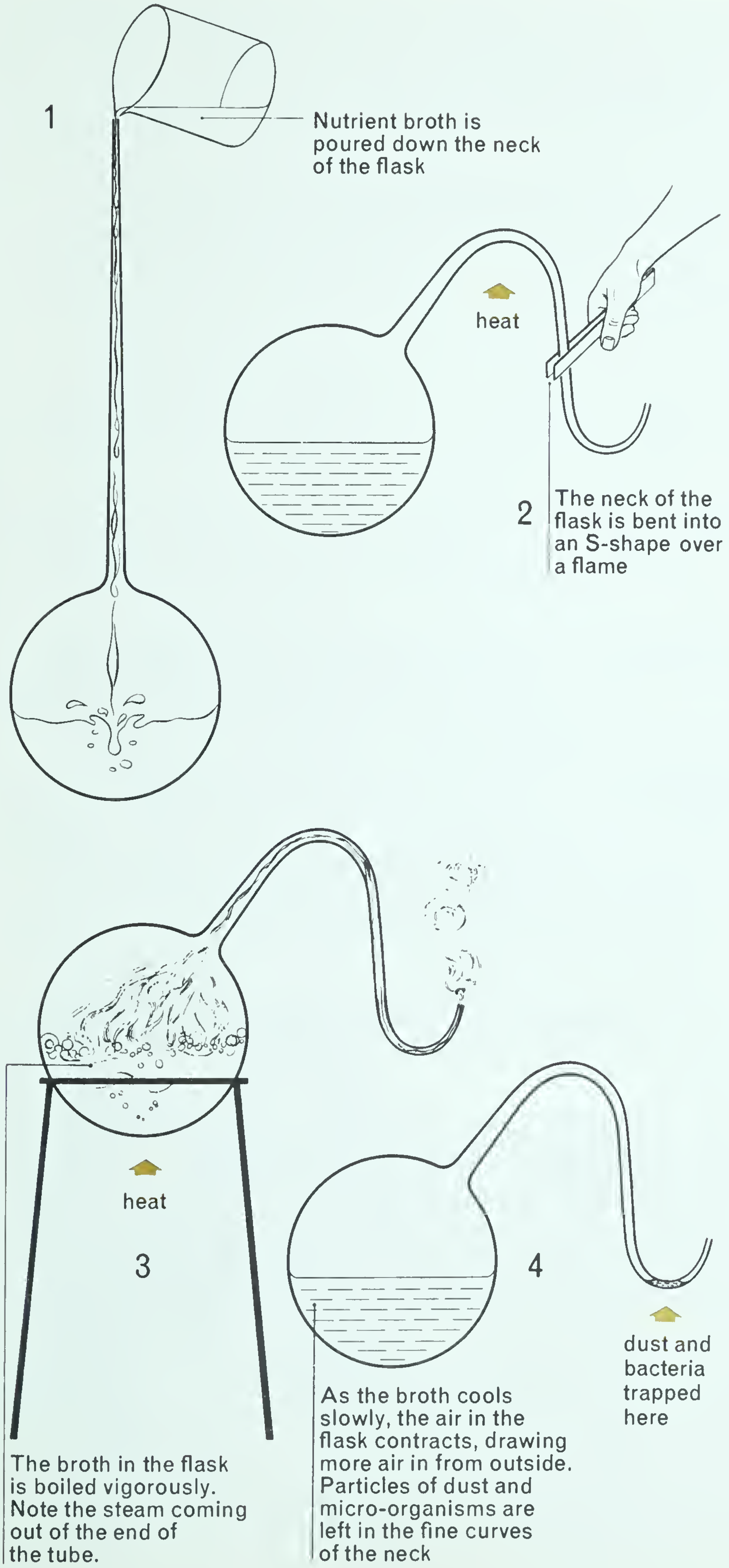


Figure 10
Pasteur's famous culture flask.
Mansell Collection.



Nutrient broth is poured down the neck of the flask

The neck of the flask is bent into an S-shape over a flame

The broth in the flask is boiled vigorously. Note the steam coming out of the end of the tube.

As the broth cools slowly, the air in the flask contracts, drawing more air in from outside. Particles of dust and micro-organisms are left in the fine curves of the neck

dust and bacteria trapped here

Figure 11
How Pasteur set up his flask.

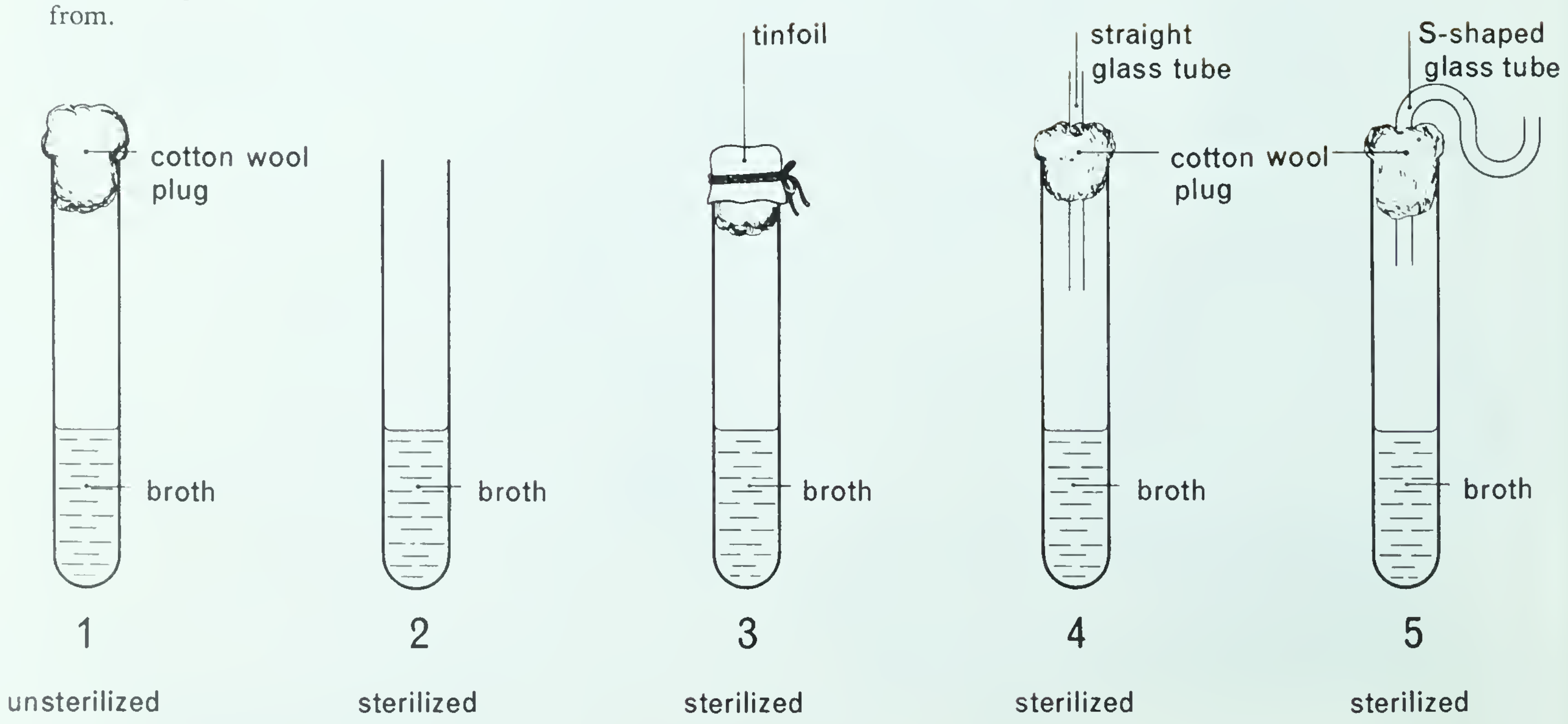
fine curves of the neck. Pasteur then went on to show that if he cut off the neck of the flask, or if the flask was tipped so that the broth was allowed to come into contact with the dust in the neck, bacteria would appear in the broth within a few days. See figure 11.

By this series of experiments, Pasteur had shown that microbes exist in the air but that they cannot arise on their own.

1. You can try some similar experiments for yourselves. Into five test-tubes pour nutrient broth to fill each test-tube to about one-third. Then set them up as in figure 12.

Test-tube 1.	Plug with sterile cottonwool but do not heat.
Test-tube 2.	Heat in a pressure cooker for fifteen minutes to sterilize. Leave unplugged.
Test-tube 3.	Plug with sterile cottonwool and tie several layers of tinfoil securely over the cottonwool. Heat in a pressure cooker for fifteen minutes to sterilize.
Test-tube 4.	Plug with sterile cottonwool through which an open straight glass tube has been inserted. Heat in a pressure cooker or autoclave for fifteen minutes to sterilize.
Test-tube 5.	Plug with sterile cottonwool through which one open end of an S-shaped fine glass tube is inserted, the other end also being open to the air. Heat in pressure cooker or autoclave for fifteen minutes to sterilize.

Figure 12
Discovering where bacteria come from.



2. Number all the test-tubes and place them in a rack away from direct sunlight and the radiators. If bacteria are present in any of your test-tubes, they will probably turn the broth cloudy, or *turbid*. The amount of cloudiness is a rough indication of the number of bacteria present, and it will be important, also, to note when the broth starts to go turbid.
3. Record what you see on the third, fifth, and seventh days after you have set up your experiment, and again after two weeks.
4. Make a table of your results which might look something like this:

	Day 3	Day 5	Day 7	Day 14
Test-tube 1	Turbid	Turbid	Very turbid	Very turbid
Test-tube 2	Clear	Clear	Slightly turbid	Turbid
Test-tube 3	Clear	Clear	Clear	Clear
Test-tube 4	Clear	Clear	Clear	Slightly turbid
Test-tube 5	Clear	Clear	Clear	Clear

What conclusions can you draw from your results? For instance, did the fact that the broth in test-tube 1 was not sterilized have any effect on the speed with which the broth went turbid?

The broth in test-tube 2 was sterilized. If it went turbid why was this so? What did your results in test-tubes 3 and 5 show? Did you get the same results in each of these tubes? If so, can you explain this?

What were the results in test-tube 4? Did it act as a control for test-tube 5? Tube 5 is really a copy of a Pasteur flask. How could you prove that bacteria, if present in the air, have not reached the nutrient broth?

Why did Pasteur's experiments succeed in disproving the theory of spontaneous generation when Spallanzani's did not?

Summary

In our practical work we have learned that micro-organisms can be either microscopic fungi or even smaller single-celled organisms called bacteria. We have shown that they exist in large numbers in the soil and in the air. Some are dangerous, some are useful. Most important of all, we have found that bacteria do not form on their own from substances which are sterilized; in other words, they cannot arise spontaneously.

Chapter 2

Growing bacteria

2.1 Early discoveries about growing bacteria

Louis Pasteur was a great experimenter. He saw clearly that one of the first steps in the investigation of micro-organisms must be to settle the question of whether they arise spontaneously or whether they come from other microbes like themselves. He was more interested in what bacteria do than in what they looked like and how they could be grown.

About the time that Pasteur had become famous for his experiments (which showed, among other things, that micro-organisms could not arise spontaneously), a German called Robert Koch (1843–1910) (see figure 13) was busy experimenting in a small

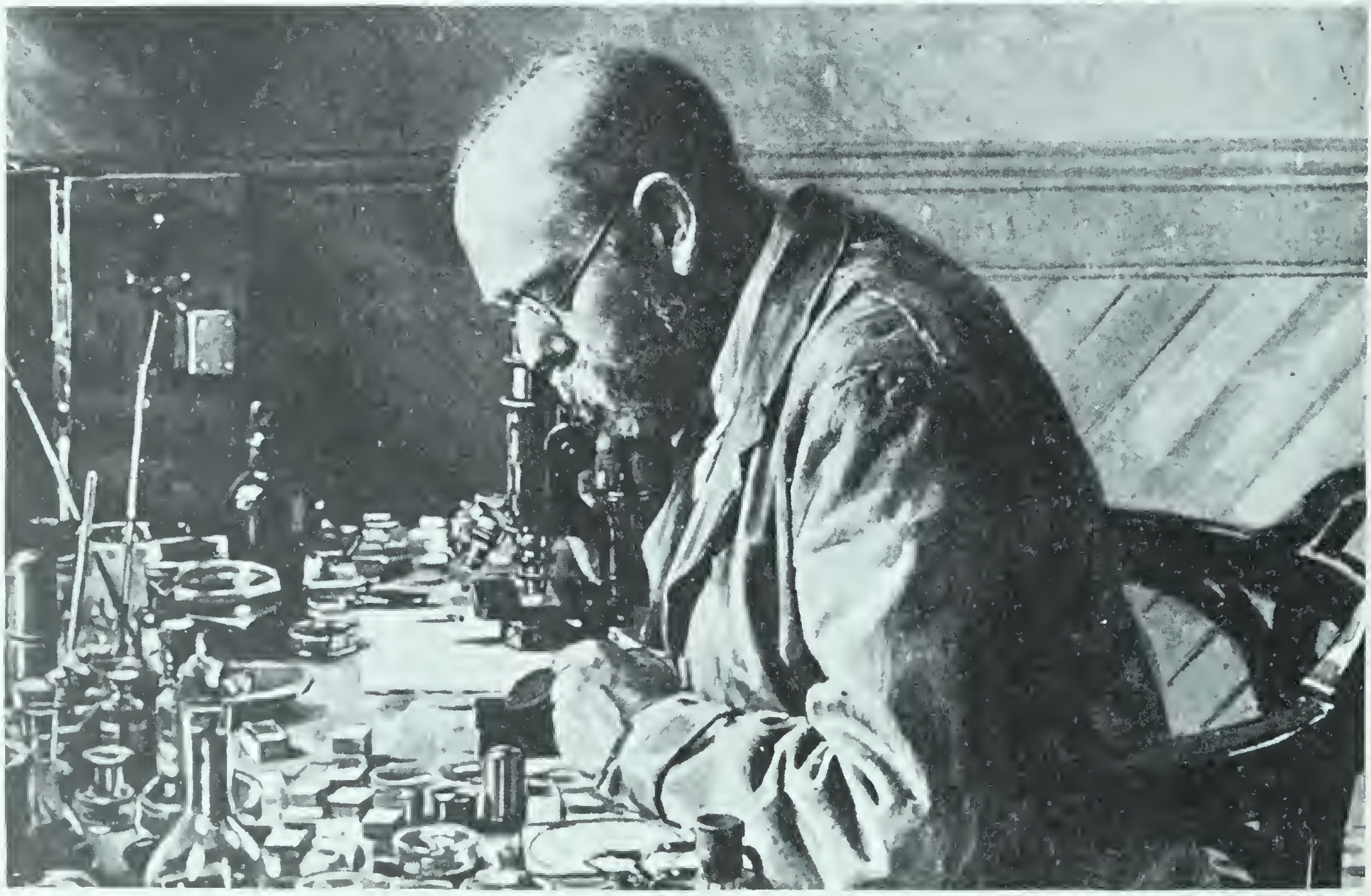


Figure 13
Robert Koch (1843–1910) in his laboratory. He is looking at one of his cultures under the microscope. Compare this microscope with Leeuwenhoek's (see figure 3).
Mansell Collection.

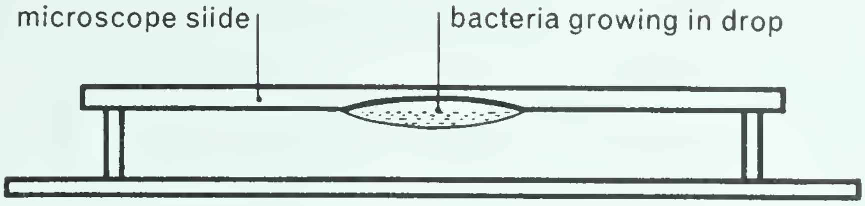


Figure 14
Robert Koch's 'hanging drop' slide.

laboratory in his garden. He wanted to know how bacteria lived, and how they could be grown. Working completely on his own, Koch found ways of growing bacteria. Since he was interested in those found in diseased animals, he looked for methods of cultivating bacteria in such a way that he could watch their growth under laboratory conditions. So he infected a drop of liquid from the eye of an ox and placed the drop on top of a microscope slide in which there was a shallow cavity. He then turned the slide over so that the drop hung suspended (see figure 14). Under his microscope he watched bacteria grow, forming more and more bacteria. He even made the first photographs of bacteria through his microscope.

Later, Koch improved his methods of culturing bacteria by growing them on plates of jelly. This made it possible for Koch to study their shapes more easily with a microscope and also to select, from the jelly plates, different kinds of bacteria and to grow each separately. These are called pure cultures, and Koch's methods are still those used by bacteriologists today.

2.11 Microbiological techniques

You are going to make cultures of bacteria using nutrient agar as a growing medium. This is really a kind of jelly containing beef extract and other substances upon which bacteria feed. The agar, which is extracted from seaweed, forms a jelly at room temperature.

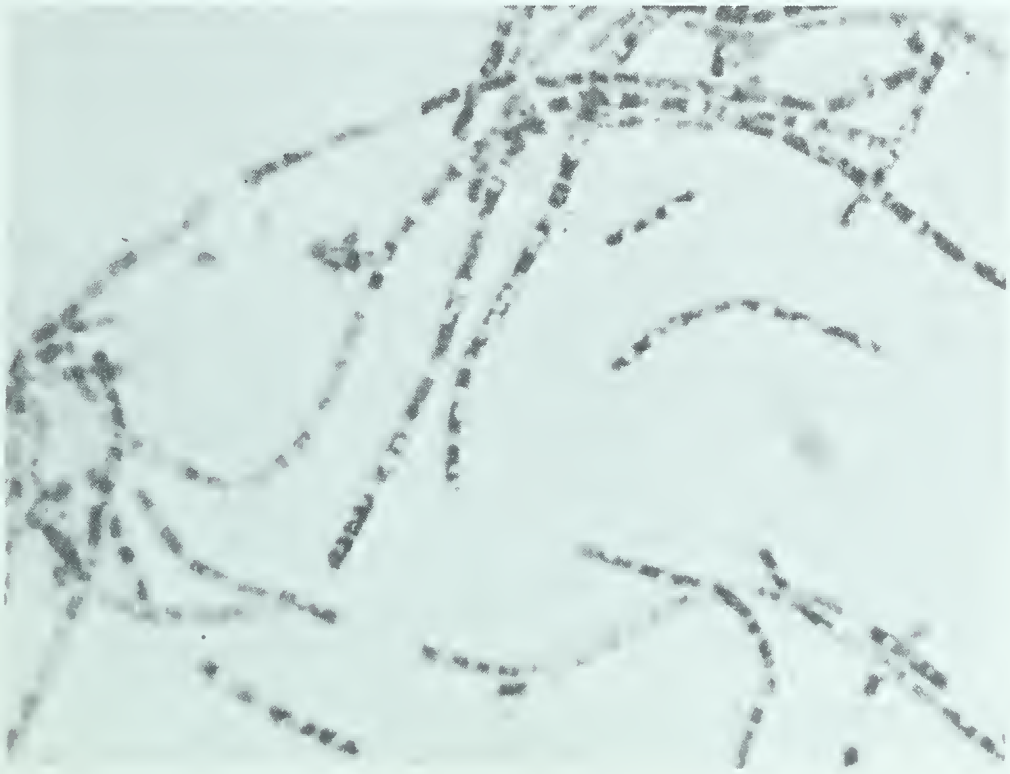


Figure 15
A culture of anthrax bacilli × *2,000*. Note how the bacilli of anthrax grow in strings. The round black dots are spores (a resting stage) which can remain alive for a long time. *Photo, Flatters & Garnett.*

It is important to observe strict rules of cleanliness while you are preparing the experiments. We know from Pasteur's work that bacteria occur almost everywhere. So that if we are going to grow bacteria on Petri dishes, or 'plates' as they are usually called, we must make sure that there are no bacteria on the plates before we begin, otherwise we will not know which bacteria are which.

Here are some rules which you should follow:

1. Always wash your hands immediately before you touch the Petri dishes.
2. Once the lid of the Petri dish containing the agar is lifted off, do not breathe or cough nearby. (Why not?) Replace the lid as quickly as possible.

Special precautions

Remember that after a few days there may be large numbers of bacteria growing on the agar, some of which might be harmful and could give you a sore throat. So you should follow these simple rules:

1. After you have finished with a culture, place the whole Petri dish, lid, and base, in a container of disinfectant.
2. Avoid all hand-to-mouth operations, such as eating food or licking labels, until you have washed your hands.
3. Avoid breathing over the culture while the lid is off the Petri dish.
4. Wash your hands before leaving the laboratory.

Recording your experiments

In all of these experiments you will be using several Petri dishes and inoculating them in different ways. It is important, therefore, to label each plate as it is inoculated so that you will know which is which when it comes to recording results. Keep careful records so that you can look at them before answering questions and drawing your conclusions.

2.12 Growing bacteria from the air

We have already proved (see section 1.3) that bacteria are present in the air. Do they occur everywhere or are there more in some places than in others? Perhaps we can grow these bacteria on nutrient agar and find out where they are abundant and where they are rare. We could try, for instance, the air of the laboratory in a draughty place and in a still place. We could test the air out-of-doors and compare it with air in the laboratory.

You will be provided with Petri dishes containing sterilized agar. The dishes have also been sterilized.

1. Label the plates 1, 2, 3, and 4 with a Chinagraph pencil.
2. Choose a draughty place in the laboratory, take off the lid, and expose the agar of plate 1 to the air for twenty minutes.
3. Choose another place in the laboratory, away from draughts, and

expose plate 2 to the air for twenty minutes. You could make a draught screen for this plate by surrounding it with a ring of cardboard.
4. Expose plate 3 outside for twenty minutes.
5. Do not expose plate 4 at all.
6. Bacteria grow best at about 37° C, so place the plates in an incubator, at this temperature.
7. After two days, remove the plates from the incubator. If bacteria have fallen from the air onto the exposed plates they will grow into colonies and, since the agar is transparent, there is no need to lift the lid off the Petri dish to see them. Place the whole plate on a piece of black paper and the colonies will show up beautifully.

a. Is there any difference between the numbers of colonies on the three plates?
b. If so, can you explain this result?
c. What was the purpose of plate 4?

2.13 Bacteria on ourselves

Before having a meal, we are taught to wash our hands. You have also been asked to wash your hands before starting any of these experiments. If you have been cleaning your bicycle or playing football, your hands may *look* dirty. But are there bacteria on our hands, and are there more bacteria on unwashed than on washed hands? We could find out by trying to grow bacteria from our fingers on agar.

For this experiment you can work in pairs and one member of each pair, quite contrary to the instructions given in section 2.11, should *not* wash his hands before the experiment. You will be provided with three Petri dishes A, B, and C, containing sterilized agar as in section 2.12.

1. Label the three Petri dishes *A*, *B*, and *C*.
2. Plate A. The person with washed hands opens *A*, while his partner, with unwashed hands, very gently presses the fingers of one hand onto the medium so as not to damage the surface. Replace the lid quickly.
3. Plate B. The person with washed hands opens the lid and presses the fingers of one hand very gently on the medium and then quickly replaces the lid.
4. Plate C. Leave unopened.
5. Put the plates in the incubator at 37° C.
6. After two days examine the plates on a sheet of black paper as you did in section 2.12.

a. Have any bacteria grown on *A* and *B*?
b. If so, are there more bacteria on *A* than *B* or the reverse? How do you account for the result?
c. What was the purpose of plate *C*?
d. Have any bacteria grown on *C*? If so, can you give any explanation?

You could also try making a fingerprint after you have dried your hands on (*a*) a dirty towel, (*b*) a paper towel, and (*c*) in hot air (over a Bunsen burner flame turned low). What might the results show?

2.2 Are there bacteria in milk?

So far we have been finding out about bacteria in the air and on our skin. But there must be many more places in which bacteria abound. The problem of keeping food free of bacteria is sometimes difficult to solve, but here again, Pasteur's discoveries have come to our aid. One such problem concerns the freshness of milk.

Milk is a mixture of a number of substances such as sugars, fats, and proteins. It is often called a complete food, and this is certainly true for young mammals. On the other hand, we all know that if milk remains for any length of time in a warm kitchen, it will turn sour. This is why it should always be kept in a cool place. This suggests that bacteria might be present, but you could test this hypothesis by trying to grow them from a sample of milk. To do this you will make what is called a streak plate.

You are provided with two sterilized Petri dishes containing sterile agar, an inoculating loop, and a test-tube containing a much diluted sample of milk.

1. Sterilize the inoculating loop by holding it in the flame of a Bunsen burner until it becomes red hot, and then allow it to cool. While cooling, the needle should be placed so that it is not in contact with the bench.

2. To make a streak plate, dip the sterilized inoculating loop in diluted milk and, lifting the lid of the Petri dish with one hand, streak the surface of the agar as in figure 16. Be careful to hold the inoculating loop nearly horizontal and stroke the agar on the plate lightly. Do not dig into it.

3. Replace the lid quickly and label this plate *A*.

4. Label the other plate *B* and leave it as it is.

5. Place *A* and *B* in an incubator at 37°C for thirty-six hours.

By incubating the plates we shall be growing any bacteria that are there, just as we tried to grow bacteria from the air and from dirty hands (see section 2.13).

6. After thirty-six hours, examine the plates. If bacteria were present in the milk, they will have formed colonies. The agar used in this experiment is of such a kind that when bacteria feed upon it, they turn a pinkish-red colour. They can then be seen easily without standing the plate on black paper as you did before.

The plate *A* was the one inoculated with milk. Are there any pinkish-red dots on the surface? *B* was not inoculated and acted as a control. If any colonies of bacteria have grown on it, what explanation can you give?

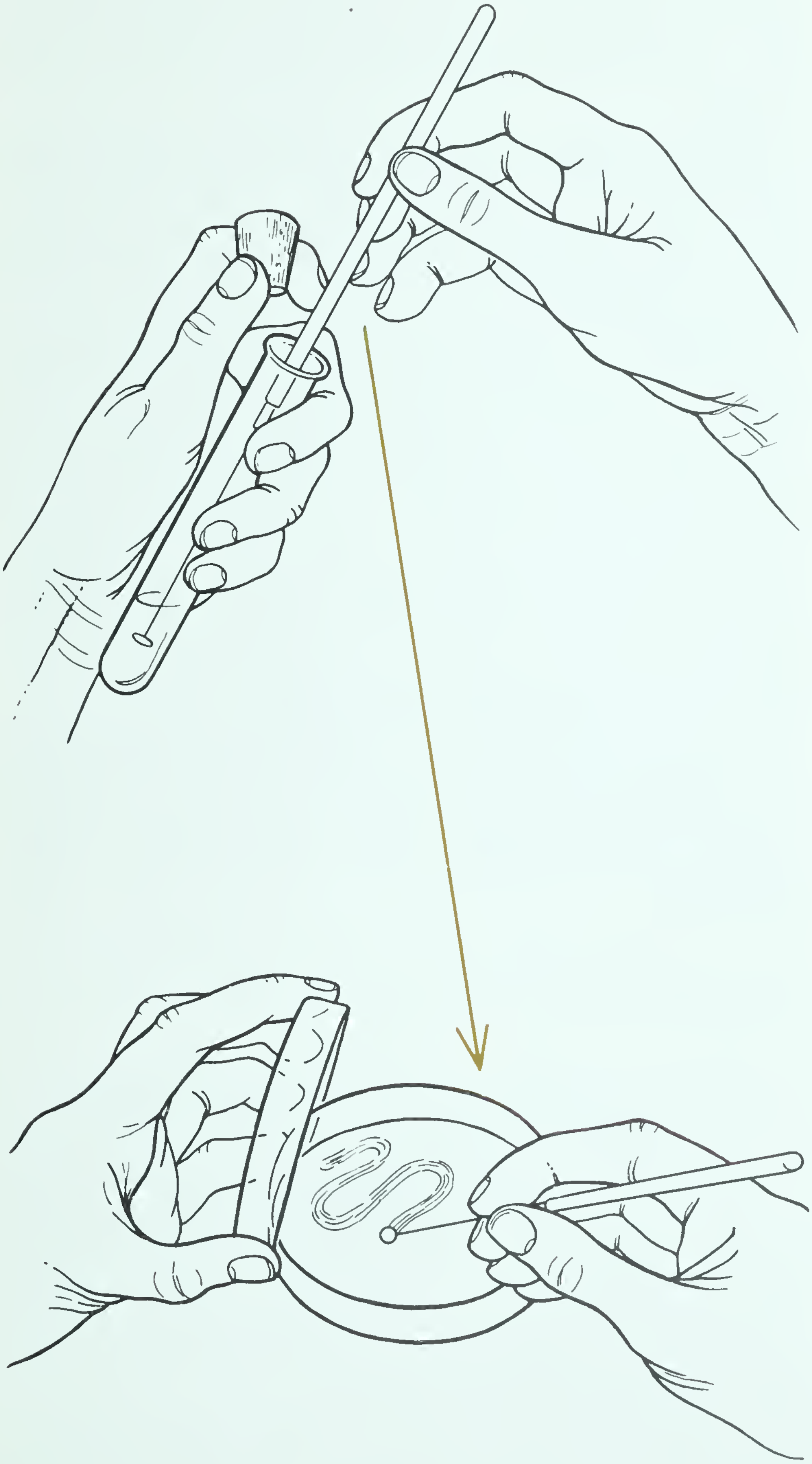


Figure 16
Making a streak plate. Notice that the inoculating loop is held nearly horizontal so that it does not dig into the agar plate.

2.21 Pasteur discovers why wine can go sour

We know from this experiment that if there are bacteria in milk, keeping it warm will encourage them to grow faster and form colonies quickly. Milk taken straight from a cow after milking will be at about the same temperature as the body of the cow – that is, about 41°C.

This is the temperature at which we have been growing bacteria. Thus the first thing the dairyman must do after milking is to cool the milk by passing it through a special cooling machine before it is put into churns. By keeping the churns cool, especially in summer, the freshness of milk can be prolonged and the growth of bacteria slowed down.

During the last century the same problem was experienced by wine growers in France. They found that the wine turned sour in their storage vats after a time, especially in warm weather. It had started to turn into vinegar. They asked Pasteur to investigate the trouble. He set up a makeshift laboratory in an old café in one of the wine growing districts of France. Taking samples of wine, he surprised the local wine growers by telling them which samples were going to turn bitter and which would remain good. The wine growers thought of Pasteur as a magician but there was really nothing miraculous about it. He simply examined the different samples of wine under a microscope and made his forecasts from the sorts of bacteria and the numbers that he found.

After several attempts to solve the problem of how to stop the action of bacteria in wine, Pasteur finally hit on the idea of heating it to a temperature of 60°C and then cooling it again. This killed off many of the harmful bacteria and made it possible to keep the wine almost indefinitely. Today this process is called *pasteurization* after Pasteur.

2.22 Can we improve the keeping qualities of milk by pasteurization?

Perhaps we can apply the same methods to milk and see if, by heating samples of new milk, we can keep it fresh for longer?

1. Pour raw milk into each of six 1 oz McCartney bottles, to fill them just to the bottom of the screw. These are small bottles with a screw cap fitted with a rubber lining, so that they are watertight.
2. Label three bottles A, and put them in a water bath at 63 C. Keep the bath at that temperature for thirty minutes. The bottles must be completely covered by the water.
3. Take the three bottles labelled A out of the water bath and cool them rapidly under running cold water.
4. Label the other three bottles B and leave them as they are.

Thus we have two sets of milk samples. One (batch A) has been heated and cooled. The other (batch B) has not. We can now see if keeping these samples of milk at different temperatures, for the next two days, has any effect on them.

5. Place one sample from each batch in a refrigerator, one from each batch in a warm place in laboratory, and the third from each batch in a shady place out-of-doors. Label each sample with the place in which you have put it.
6. After two days the samples must be tested to see if any of them have gone sour. But it is *not* a good idea to taste the samples since after two days they may have grown a lot of bacteria. When milk goes sour it curdles, and if sour milk, or even milk on the point of turning sour, is boiled, the curds turn to clots. Fresh milk will not clot on boiling. Thus all we have to do now is to boil milk from each sample in a boiling tube, taking great care to heat the milk in the tube very slowly. In the form of a table, like the one below, record whether the sample has clotted or not.

Situation	*Sample A*	*Sample B*
Refrigerator		
Warm place		
Out of doors		

From your results would you say that the milk you heated and cooled kept better than that which was unheated?

What you have done in this experiment is to 'pasteurize' the batch A of milk samples. Nowadays, nearly all milk from dairies is pasteurized as a safeguard against harmful bacteria and also to improve its keeping quality. (Unpasteurized milk can grow up to twenty million bacteria per 1 cm^3 in twenty-four hours.) Commercially, milk is pasteurized either by heating to 63°C and keeping it at that temperature for thirty minutes, or by what is called the 'flash' method, in which it is heated to 72°C for fifteen seconds.

2.23 Testing milk for freshness

The 'clot on boil' test which you have just carried out (see section 2.22) is used by milk testers to see if samples from churns are turning sour. But this takes rather a long time, because the milk has to be kept for at least twenty-four hours before the test can be made. A much quicker test makes use of a dye called *resazurin*. When resazurin is added to a sample of milk it turns the whole sample blue. This colour will not change, on heating the milk, if there are only a few bacteria present. But if the number of bacteria is large the colour quickly changes on heating from blue to pink and finally to white. This happens because bacteria contain a substance which causes a change in the colour of the dye. As the bacteria multiply, the more rapid will be the change in the colour of the resazurin from blue to pink to white.

This dye will provide a means of testing the freshness of samples of milk.

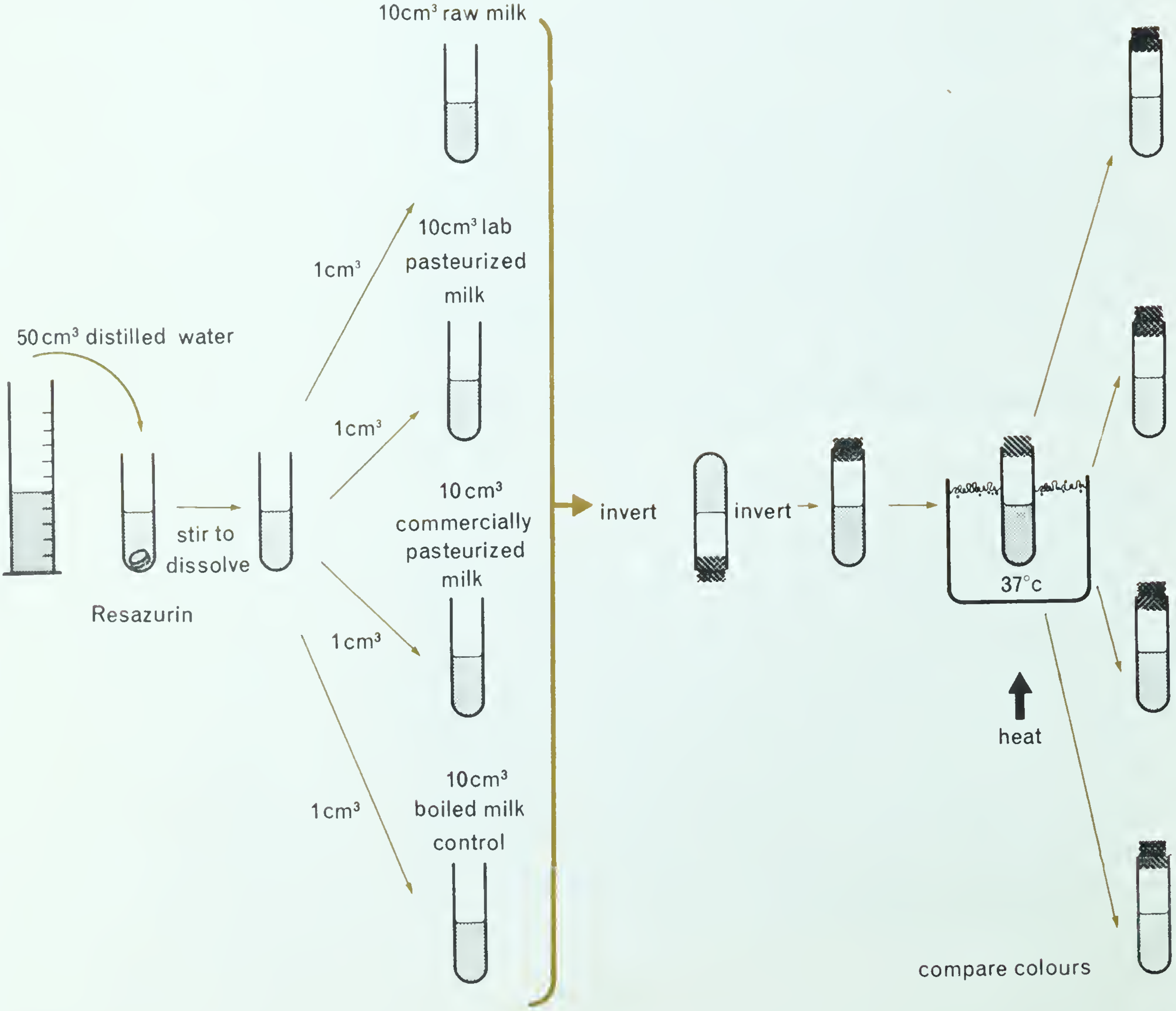
You can compare the results obtained by testing milk pasteurized in your laboratory, raw milk, and commercially pasteurized milk.

Since the samples of milk you produced were already two days old before you did the 'clot on boil' test, you will have to use fresh samples for this test. You could test the following:

a. Fresh raw milk.
b. Fresh laboratory pasteurized milk.
c. Fresh commercially pasteurized milk.

1. Dissolve one tablet of resazurin in 50 cm³ distilled water.
2. 1 cm³ of this solution is then added to 10 cm³ of milk to be tested, in a sterile boiling tube which is then sealed with a sterile rubber bung.
3. Each boiling tube is labelled and turned over once to mix the contents.
4. It is then incubated in a water bath at 37°C, filled so that the level of the water is just above that of the milk in the test-tubes.

Figure 17
The stages in testing milk for bacteria using the dye resazurin.



5. A control tube is also set up in exactly the same way except that boiled milk is used instead and also incubated in the water bath.
6. After ten minutes withdraw the tubes and note any colour change.
7. The tubes are replaced and after an hour they are examined again.
8. The colour of each tube is then compared with the control in which boiled milk was used and in which you would expect no change from the original blue colour.

If there is any change from blue, through purple to pink (or even to white) in either of the pasteurized samples, can you offer an explanation? Why does the boiled milk not change colour?

Figure 17 shows, in the form of a diagram, the stages of testing milk using resazurin.

Summary

We have been growing bacteria from various places such as the air, our own bodies, and milk, and finding out that, given the right food, they will multiply very quickly. But we have also been concerned with learning how to prevent bacteria from growing where we do not want them. We have employed various ways of destroying bacteria. The use of heat to do this is called *sterilization*. In everyday life we often make use of these ideas in such ways as washing ourselves and our clothes and in the preparation of our food.

Background reading

Louis Pasteur

The great French chemist and biologist Louis Pasteur was born in 1822 at Dôle, not far from the border between France and Switzerland. His parents were peasants and his father, a tanner by trade, had fought for the Emperor Napoleon. Pasteur went to school in Arbois, but did badly – he much preferred to go fishing. His headmaster fortunately recognized that although he was slow, Pasteur showed promise. He therefore encouraged him to go to Paris and to study there. So when Pasteur was fifteen, he set off for Paris hoping to prepare for his entrance exams, but was homesick and eventually his father brought him home again. After studying locally at Besançon, he was determined to try again in Paris, and entered the famous École Normale. Although he worked with enthusiasm during his student days, Pasteur was only considered 'mediocre' in chemistry.

When only twenty-six years old, Pasteur solved a problem that had been puzzling all the great chemists of the day. Tartaric acid, found in wine dregs, produces a strange effect when light passes through it. He showed that this is because the acid is, in fact, a mixture of different acids. Biot, a great chemist, could not believe that Pasteur had solved the problem and insisted that he should repeat the experiments at Biot's home. When Pasteur did this successfully, Biot exclaimed to him, 'My dear child, I have all my life so loved this science that I can hear my heart beat for joy!'

By now a young man of reputation, he was appointed to the University of Strasbourg as a professor and soon afterwards he got married. It is said that he was so absorbed in his work that someone had to go to his laboratory to make sure he remembered his wedding day! All the same he had a long and happy marriage.

At Strasbourg he became interested in fermentation, and continued this work when he moved on to the University of Lille. He found that the changes brought about in the fermentation of beer or wine, the souring of milk, or the decay of meat, occur when special micro-organisms are present and as a result of his studies he was asked to help at breweries where the fermentation of beer had gone wrong. When he put a drop of bad beer on a slide and looked at it under the microscope, he discovered that, instead of round yeast cells, the beer contained small rod-shaped bacteria. Not only are micro-organisms necessary in fermentation, but they also have to be the right ones. Pasteur helped brewers to culture the right organisms for good beer and made brewing a more scientific procedure. He also helped the wine industry by showing that if wine is heated to 60°C for a short time, the growth of harmful bacteria is prevented, and the wine does not go sour in bottles or barrels.

Pasteur was devoted to France and to his fellow men, and liked his work to benefit ordinary people, but he realized the wider applications of his discoveries. His studies on fermentation showed that life can only come from life. The supporters of the theory of spontaneous generation who maintained that living things could arise from dead matter he proved to be wrong.

By 1857 Pasteur had become world famous, and was now appointed a director of studies at the École Normale in Paris. He was asked to help investigate a serious disease that was ruining the silkworm industry in France and the rest of Europe. At first he was not particularly interested in the problem, but when he saw the misery and hardships of the silk growers in the south of France, he set up a laboratory near the silk farms. The signs of the disease were that the eggs did not hatch, or the worms (actually the caterpillars of the silk moth, *Bombyx mori*) would die before making their silk cocoons. As a remedy the French farms imported eggs from Italy and Spain, and these eggs gave excellent silk to begin with. But the disease spread and by 1864 there were no uncontaminated eggs left except those imported from Japan. As the epidemic had raged for fifteen years numerous cures had been suggested and hundreds of papers written about it. Various cures were suggested, such as feeding the grubs on special diets – some of these even including such unlikely remedies as wine and rum.

Using his microscope Pasteur showed that the diseased caterpillars and eggs all contained tiny organisms. He managed to get some healthy worms and dividing them into two lots fed them on mulberry leaves. One lot of leaves was smeared with remains of diseased worms, while the others were smeared with remains of healthy ones. Pasteur showed that the worms fed on leaves coated with diseased remains became diseased themselves, while the controls remained healthy. As a result of this discovery, he worked out a simple way of keeping silkworms under healthy conditions so that they did not become infected by bacteria. Not only was the silk industry of France saved from disaster, but Pasteur had shown that the disease from which the silkworms suffered was due to bacteria.

By his work on silkworms, Pasteur had established the connection between bacteria and disease – a most important discovery. Accounts of Pasteur's work were read by a famous Edinburgh surgeon, Lord Lister, who was much concerned about the number of people who died from infection after having an operation in hospital. By using disinfectant sprays during an operation, Lister prevented bacteria from entering a wound. Many other improvements were brought about by the introduction of sterile methods which reduced the number of hospital deaths.

Pasteur was deeply interested in the practical, useful side of his discoveries. He enjoyed working out the right way to make good beer, good wine, and good vinegar. But his greatest contribution as a scientist was that he could look beyond the result of one problem and relate the findings to many others. He had a wonderful ability for guessing a possible solution to a problem – making a hypothesis and then designing experiments to prove it right or wrong. Much of his success depended on his great skill in designing apparatus that was simple and fool-proof, and which gave clear and conclusive results. His work carried out a century ago, provides the foundation of bacteriology today. When he died in 1895, Pasteur was much respected and well-loved.

Chapter 3

Bacteria and health

3.1 Bacteria in millions

We have seen how quickly bacteria can grow and multiply in a liquid food such as broth or milk. But can they go on multiplying for ever?

Imagine one bacterium in the middle of a Petri dish containing a jelly broth. If we left the dish in a warm room for half an hour there would be two bacteria, after the next half hour each of these bacteria would have divided and there would be eight, then sixteen, then thirty-two and so on. If all these bacteria lived, how many do you think there would be at the end of twenty-four hours? You will find this a very long calculation which will give you a very long answer.

If these tiny microbes can multiply at this rate, you may wonder why they don't quickly cover the whole surface of the earth. Fortunately this cannot happen; for one thing their food supply would soon run out and, for another, they are eaten in huge numbers by many small animals. They also suffer from various diseases, like ourselves, and can be wiped out in millions.

Now you can see how food such as milk and meat soups on a warm day can easily grow millions of bacteria and turn the food 'bad' or sour in a very short time.

3.11 Clean air

Our experiments with bacterial plates have already shown us that bacteria and many other kinds of micro-organisms occur in the air. If this is so, a further question we could ask is where do all these microbes come from? We have already provided part of the answer, for we know from experiment 2.13 that we ourselves can be good sources, partly through our breath and partly from the surface of our bodies (particularly when we have not washed!).

If we wanted to find out more about what kinds of bacteria there are in our breath and which, if any, are capable of causing disease, we might use an apparatus similar to that shown in figure 18. The air breathed out by the man sitting in the enclosed chamber is

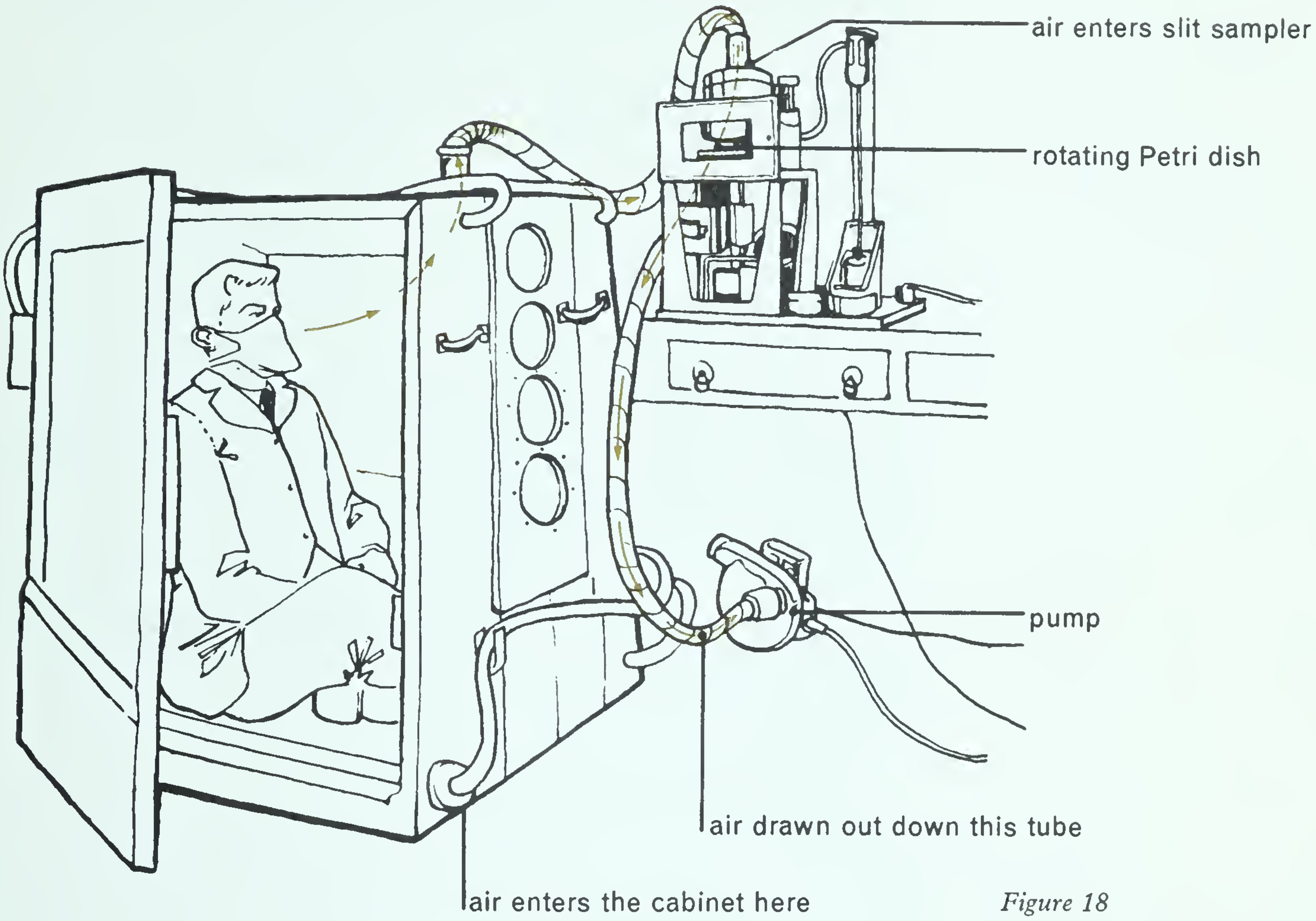


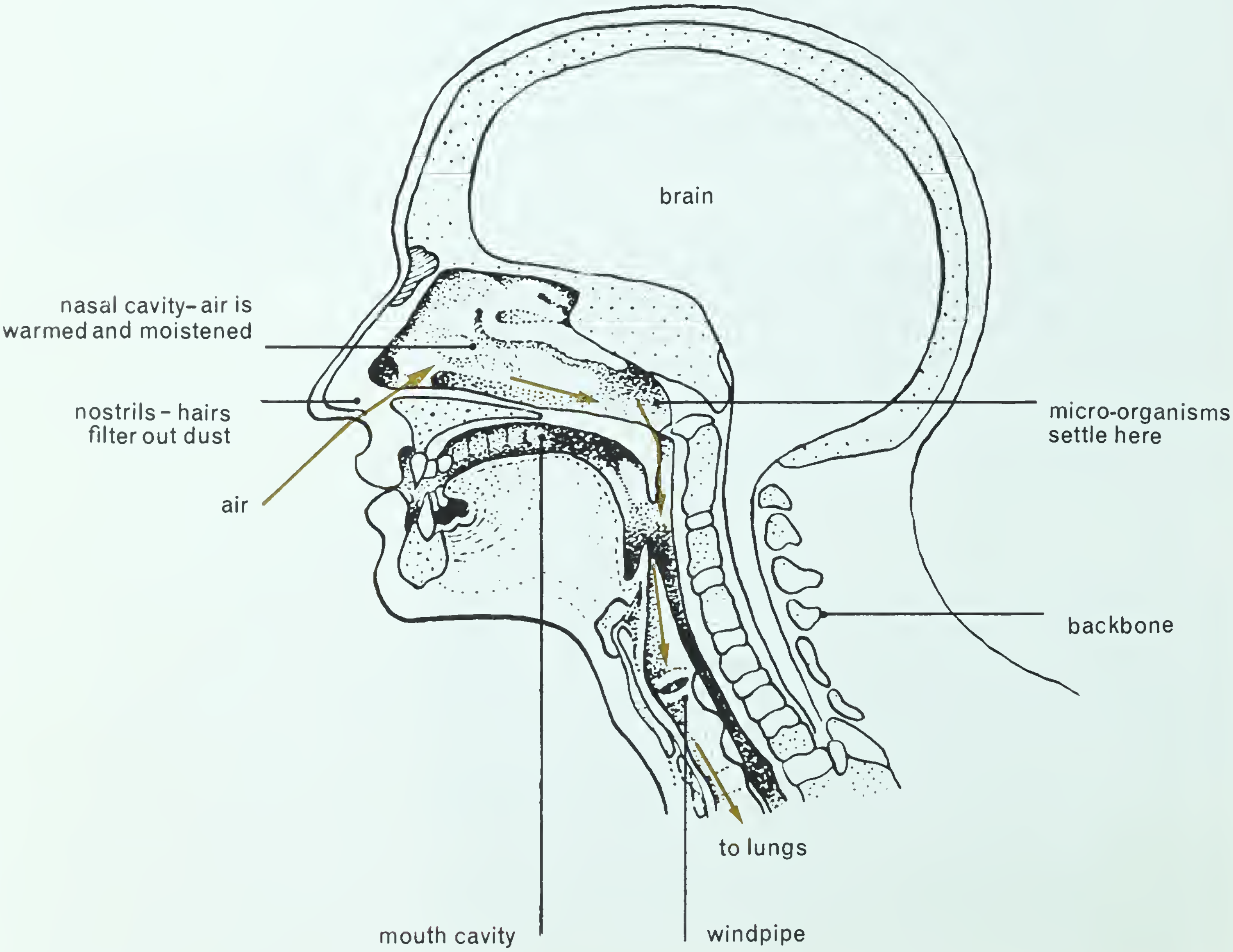
Figure 18
An air-filter apparatus. The air breathed out by the man shut up in the cabinet is drawn through the chamber standing on the table, by means of the pump.

drawn, by means of a pump, through a chamber in which there is a Petri dish containing nutrient medium on which the bacteria settle. The plate slowly rotates so that the whole surface of the jelly is exposed to any bacteria coming in from the man's breath. The jelly plate is then incubated, and any bacteria present will grow into colonies that can easily be seen. This apparatus, called a slit sampler, can be used to test air in factories, where a great many people may be working in one room, or it can be used in places such as hospitals, where much purer air is needed.

Many micro-organisms are so small that they can literally float in the air like minute specks of dust. When the air becomes damp, for instance in a fog or smog, the surface of each microbe becomes surrounded by a very thin layer of water. This makes it heavier and it slowly falls onto any surface nearby. A similar process occurs when we speak (or sneeze), for out of our mouth and nose there comes a fine spray of tiny droplets of water containing bacteria. These land on various surfaces and gradually dry up when the micro-organisms they contain are set free once more. Bacteria can also stick to the surface of dust particles and many micro-organisms become attached to them as they float in the currents of the air. Figure 19 shows how air is drawn into the nose and dust particles, which may have micro-organisms sticking to them, settle in the nostrils. If there are many organisms present, some may pass on till they reach the back of the throat where they may settle and cause a sore throat.

In an operating theatre, surgeons have to be careful not to breathe bacteria onto their patients, so they wear masks covering their noses and mouths. The man in figure 18 is testing the effectiveness of a mask. On the other hand, some people have to work in dusty atmospheres, for instance in quarries or wool factories, and for them, the problem is to keep the dust with the micro-organisms in it out of the nose and mouth. There are now regulations in factories and other places where a lot of people work in one room, which insist on proper ventilation and on the filtering of air entering the building, if there is a lot of dust. It is also important that there should be sufficient space between one person and another, to prevent the spread of bacteria.

Apart from opening windows to see that our rooms are well ventilated, can you think of any other way in which we can ensure that there are as few micro-organisms as possible floating about in the air we breathe?


brain
nasal cavity-air is warmed and moistened
nostrils - hairs filter out dust
air
micro-organisms settle here
backbone
to lungs
mouth cavity
windpipe

3.12 Clean water

Before the days of main water supplies, water was obtained from open wells which were often excellent sources of bacteria – as they still are in many countries in the Far East. Sometimes these wells were lined with rough stones which allowed water to drain in from the surface of the ground, carrying with it various kinds of micro-organisms which included the harmful bacteria occurring in sewage. There were often outbreaks of cholera and typhoid, both of which are diseases caused by bacteria in drinking water. In some deep wells where water filters in through sandy rock, the water is very pure.

Nowadays when we want a drink, all we have to do is to turn on a tap and draw off a glassful of clean water. But have you ever stopped to think where your drinking water comes from and how it is made fit to drink? This is the job of the water engineers and the sanitary inspectors who must ensure that the water supply to towns is free from dangerous bacteria.

Special reservoirs are built so that the mud and so forth in the streams supplying the reservoir, can settle to the bottom, carrying with it many micro-organisms. Tests are made at frequent intervals, to ensure that harmful bacteria are not present in quantities large enough to cause disease. Fortunately there is one kind of microbe, *Escherichia coli*, which although harmless is always present in our intestines. These microbes do not usually live in water but if they are found there, they show that other kinds of bacteria, which are harmful, may also be present. Because of this *Escherichia coli* is called an *indicator organism* and if it is present in a sample of water, more exact tests have to be made to find out how many other bacteria are there as well. Chlorine, which kills the harmful bacteria, is added, and this accounts for the taste you sometimes get in the drinking water of towns. You might try testing different samples of water for microbes like *Escherichia coli*, using drinking water, water from a pond, and distilled water.

3.13 Clean food

Perhaps it is not surprising that food which is good for us, also contains the things that bacteria require for their growth. Our experimental evidence certainly suggests that this is so. Thus, if we want to prevent infection and to stop our food going bad, it is unlikely that by altering its composition we shall be successful. When we were growing bacteria we incubated them at 37°C which we found was the best (optimum) temperature for growth. But when we wanted to kill the most harmful bacteria in milk we had to raise the temperature to 63°C. This was called 'pasteurization' – after Pasteur.

Modern methods of preserving food have made use of Pasteur's discovery that bacteria are present in all food exposed to the air, but that without the right conditions, they cannot grow. Canning of food is done at high temperatures which are sufficient to kill the harmful organisms without spoiling the food. The tins are sealed to prevent the entry of air and, if stored in a cool place, they will keep for years.

Just as heating bacteria speeds their growth and eventually kills them so cooling them down has the opposite effect and eventually brings their activity almost to a halt. You may have found this out for yourself in your experiment in section 2.22. Our ordinary domestic refrigerators are usually set at temperatures between 0°C and 10°C, and within this range most foods will remain fresh for days or even weeks. But they are not preserved indefinitely since some bacteria continue to grow, even though very slowly. Foods can be preserved for much longer periods if they are put into even lower temperatures. This is known as deep-freezing. Below −20°C nearly all micro-organisms are unable to grow, but they are not killed. So we must remember that once deep-frozen food thaws out the action of bacteria will proceed just as fast as before.

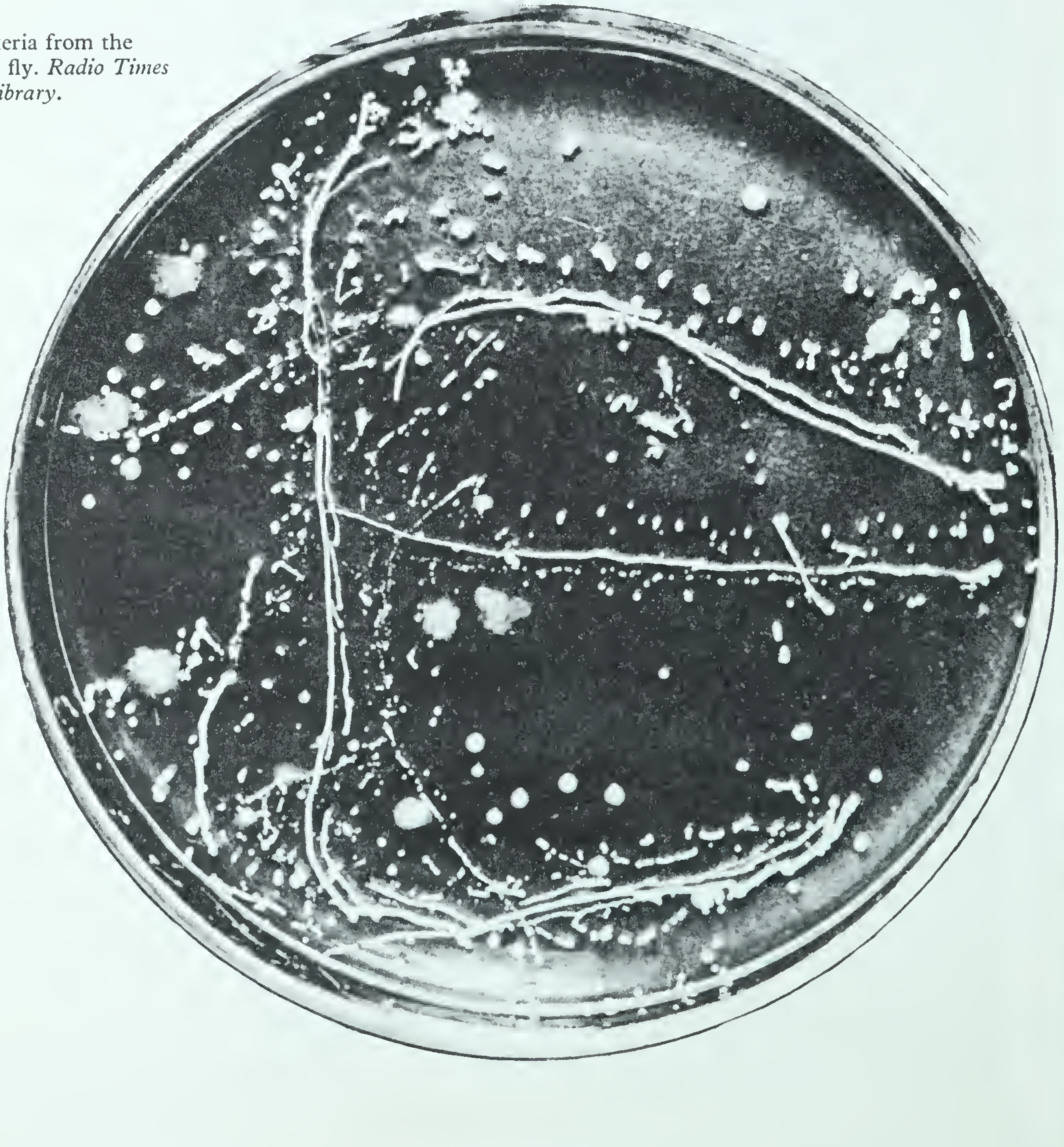


Figure 20
A culture of bacteria from the tracks made by a fly. *Radio Times Hulton Picture Library.*

In spite of our great advances in the preserving of food by heating or cooling, the fact remains that much of what we eat cannot be treated in this way. It must be eaten fresh and we must do the best we can to find ways of keeping it protected from contamination. Flies and other insects carry great quantities of bacteria on their hairy bodies and legs, and tend to be abundant during the summer. If they crawl over food after walking on some infected material they can transfer bacteria as they go. This is especially true of foods like fish and meat which are damp and to which bacteria cling easily. Eating such contaminated material can cause food poisoning, so that it is always best to keep food covered.

Figure 20 shows the tracks of a fly written, so to speak, in bacteria. A fly was allowed to crawl on a plate of nutrient agar and the result was a chain of bacterial colonies. Colonies of bacteria can grow in the same way on the surface of meat if a fly walks over it after picking up bacteria from somewhere else.

In this section we have given an outline of some of the ways in which we can help to keep the air, our water, and our food clean. But there are many more ways we have not mentioned, particularly of protecting food. Perhaps you will be able to think of some of them.

3.2 Bacteria and disinfectants

If you cut your finger it will usually heal quite quickly, but sometimes it turns septic. ‘Septic’ really means going bad and until about a hundred years ago the reason why wounds went septic was not known.

In the mid-nineteenth century, it was still quite common for people to die in hospital after an operation because of septic wounds. Pasteur had already shown that microbes in the air could turn a broth bad, and in 1865 the account of his experiments reached an Edinburgh doctor called Joseph Lister (1827–1912).

Lister was determined to discover the reason for this. He argued that if microbes from the air could turn broth bad, could they not in a similar way turn wounds ‘bad’ after an operation? The old-fashioned method of treating a patient who had a leg cut off, was to cover the wound with tar. This probably gave Lister the idea that pure carbolic acid which occurs in tar, might kill the bacteria settling on the wound from the air. He tried soaking the dressings in carbolic acid and applied them to wounds immediately after an operation and even had a spray of carbolic acid directed on the wound during the operation (see figure 21). This was successful and after two years of experimenting, Lister, in 1867, announced his discovery that carbolic acid applied to wounds would prevent them from going septic. Lister called carbolic acid an *antiseptic*, which is the name given to a number of chemicals (disinfectants) which kill germs.

Nowadays an operating theatre is quite different, as you can see from figure 22. The surgeons wear masks, sterilized rubber gloves,

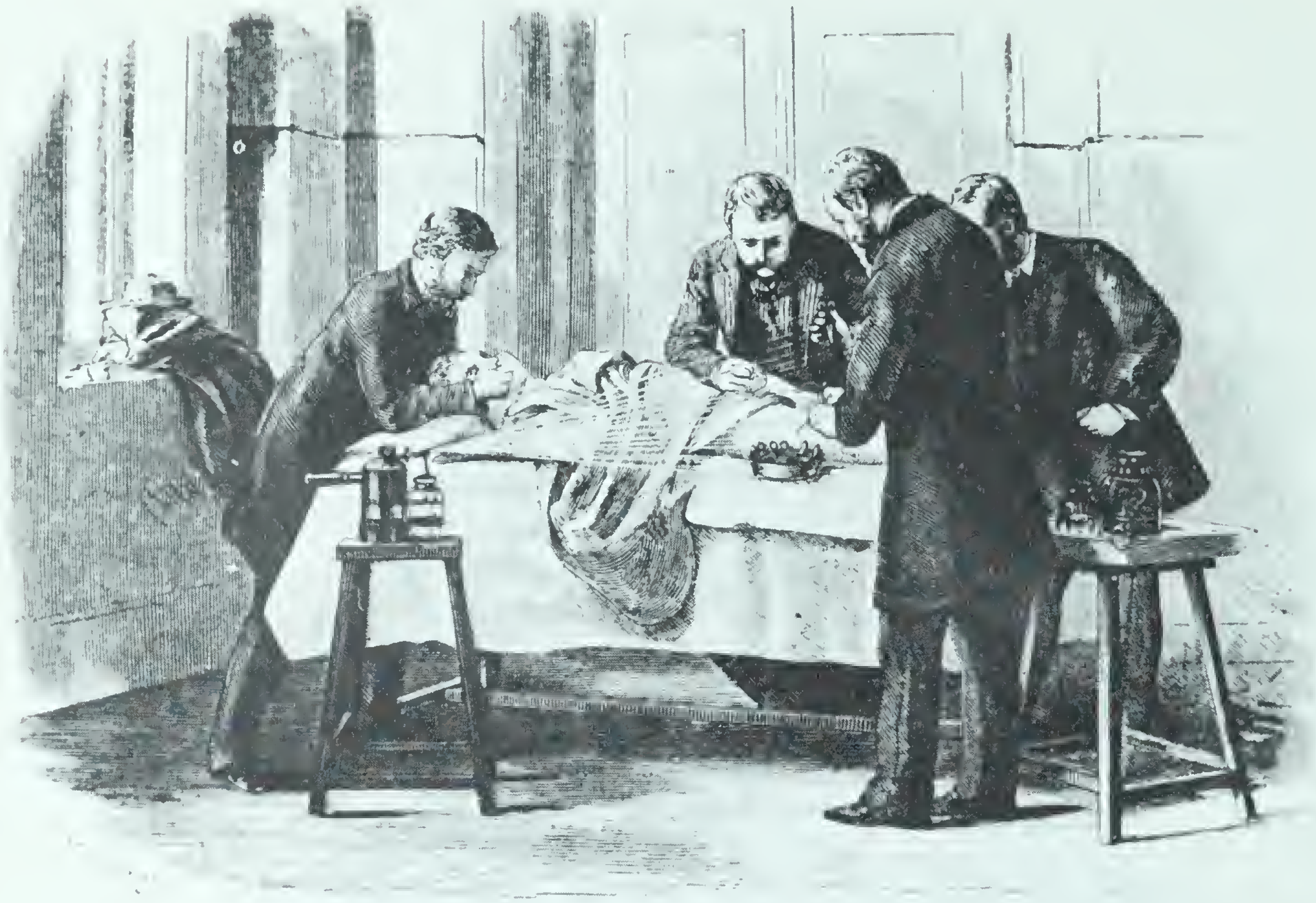


Figure 21
A surgical operation, about 1870. Notice the carbolic spray directed onto the wound while the surgeons perform an operation. They are wearing long frock coats and no masks. What other things do you notice about this old-fashioned operating theatre? *Radio Times Hulton Picture Library.*

and long overalls which have also been sterilized. The nurses are also dressed in the same way. All the dressings and operating instruments are sterilized, and the walls and floor of the operating theatre are washed down with disinfectant before the operation begins.

Carbolic acid is an unpleasant liquid to handle and Lister soon discovered that, while it certainly killed bacteria when used undiluted, it also damaged the tissues of the body. As a result wounds treated with it refused to heal, or only did so very slowly. The problem facing Lister, then, was to find the strength of carbolic acid which kills bacteria but allows the growth of tissues over a wound. We can try to solve the first part of this problem for ourselves.

3.21 What strength of disinfectant kills bacteria?

Carbolic acid is distilled from coal tar and contains a substance called phenol. Phenol is often the most important ingredient of other disinfectants which are used in hospitals and laboratories. So we could try different strengths of phenol and find out how strong it should be in order to kill bacteria. We shall use different dilutions of phenol which contains carbon. If the solution is not too strong, the bacteria can actually use phenol as food. If it is made too weak, however, there is not enough carbon for the bacteria to feed on. So we have the odd situation of a substance being a poison at a high concentration and a food when more dilute!

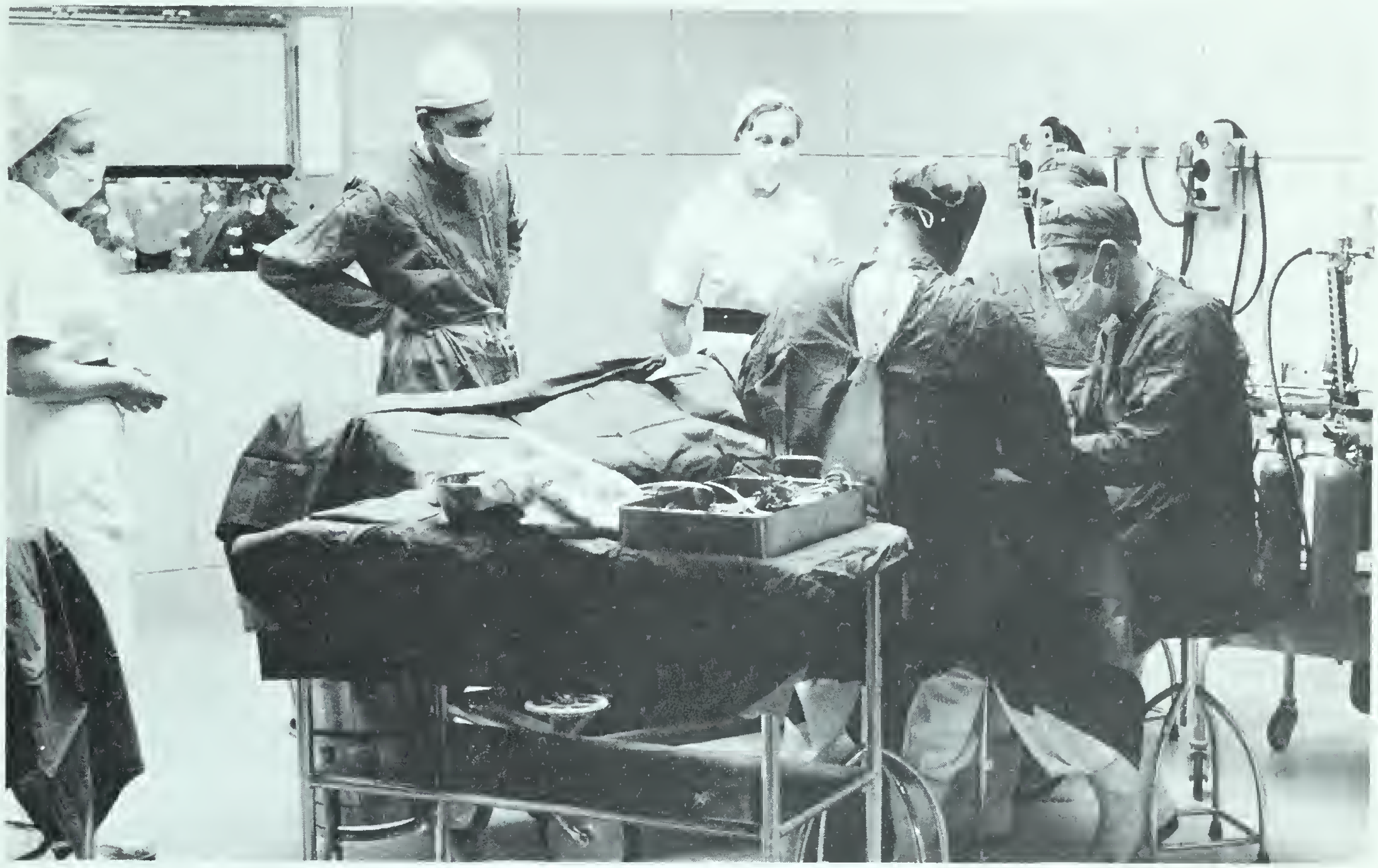


Figure 22
A modern operating theatre. Notice that the surgeons and nurses are wearing masks, that each person's hair is covered with a cap and that they are dressed in long gowns. All their clothes have been sterilized.

It is reasonable to assume, as a result of Lister's findings, that there can be no bacteria living in the concentrated disinfectant at the start of the experiment.

Soil, as we have shown already (see section 1.22), contains large numbers of bacteria, so we could use it to put into the diluted disinfectant.

You are provided with the following:

Seven test-tubes marked at two levels, and cottonwool plugs
A solution of disinfectant
A solution of soil
Distilled water
Purple indicator in a dropping bottle
A glass funnel or syringe for filling the test-tubes

This is what you must do:

1. Using a Chinagraph pencil, number the test-tubes 1 to 6 and the seventh one 'Control'.
2. Fill tube 1 up to the top mark with the disinfectant solution, using the funnel or syringe. This is the 20 cm^3 mark.
3. Into each of the other tubes, including the control tube, pour distilled water up to the first mark. This is the 10 cm^3 mark.
4. Pour half of the disinfectant solution from tube 1 into tube 2 (that is up to the top mark in tube 2). Put your thumb over the end of the tube and turn it upside down once to mix the solutions thoroughly.

5. Now pour half of the solution in tube 2 into tube 3 and mix as before. Repeat this operation into all of your tubes in turn ending with tube 6, which will now have 20 cm^3 of solution in it.

6. Pour half of this solution away. What you have been doing is to make a series of dilutions of disinfectant from your original sample in tube 1. Thus the solution in tube 2 is half as strong as that in tube 1 and the solution in tube 3 is half as strong as that in tube 2 and so on.

7. You should now mark on each tube what dilution it contains: Tube 1 will be × 1, tube 2 will be × 2, tube 3 will be × 4, and so on.

8. Now pour 10 cm^3 of the soil solution into each of the tubes, including the control tube, that is, up to the second mark on each tube, and turn each tube once upside down, with your thumb over the end of the tube, to mix the contents. Do all the tubes now smell of disinfectant?

9. Plug each tube with cottonwool to keep out the dust, and leave them for about six days at room temperature.

After this time you may find that the solution in one or two of the tubes near the middle of the series is no longer clear but has gone cloudy or *turbid*.

10. Take the cottonwool plugs out of the tubes and smell each in turn. Do those in which the solution has gone turbid still smell of disinfectant?

When soil bacteria succeed in growing in disinfectant which is sufficiently dilute, they change it into other substances which make the solution turbid and do not smell. So here are two tests – smell and *turbidity* – to tell us when we have reached a dilution in which bacteria can survive, i.e. which is no longer a disinfectant.

11. We can do another test on our series of solutions to make quite sure. The indicator in the bottle contains a purple dye which turns yellow when the amount of acid in a solution increases. When bacteria grow in a solution they can make it more acid, so we can now add two drops of indicator to each test-tube, including the control, and see which of them, if any, turns yellow. You could record your results in the form of a table like this, putting in the second column whether the solution smells of disinfectant or not, in the third column whether it is clear or turbid, and in the last column the colour changes you notice after adding the two drops of indicator. For this you should compare the colours you get with your control tube, number 7.

Test-tube	Smell, if any	Clear or turbid	Colour after adding indicator
1	Slight smell of disinfectant	Clear	Purple
2			
3			
4			
5			
6			
Control			

If the turbidity of the liquid indicates the dilution at which the soil bacteria can grow, can you think of any reason why the solution is not turbid above and *below* this dilution? Smelling the tubes may have given you the answer to this question.

Can you think of several reasons why you set up the control in Tube 7 with distilled water and not disinfectant?

Should you find that there is a marked turbidity of the weakest solutions in your series, it may be that, without knowing it, you have added other materials with the soil, providing food for the bacteria.

Suppose, however, you do get the kind of results you expect, would this be a conclusive test? Should you have made another set of dilutions exactly like the first, to make sure that the turbidity occurs at the same dilution in each set? For this purpose you could, of course, compare results with your neighbours, provided they have used the same source of soil to inoculate their tubes. It will be interesting to see if the results of the class agree.

When you added the indicator, did the tube in which you got turbidity turn yellow? Did the tubes in which you got slight turbidity turn a purple-yellow after you added the indicator? Look back to what has been said about what happens when bacteria grow in a solution and see if you can explain these results.

What other tests could you do? Do the numbers and kinds of bacteria vary in different soils, for instance? How would you test this idea? You could try other kinds of disinfectants to find out if they behave in the same way as carbolic acid and at similar or different strengths. Here, then, are two factors – soil bacteria and disinfectants. But remember that to carry out a proper scientific investigation of this kind you must only vary one factor at a time. If you vary more than one, your results will be confusing and you will really only have made a guess at the right answer.

Summary

Although this chapter has been concerned so much with the harmful bacteria in the air, in water, and in food, we must not forget that there are as many, and probably more, bacteria which are not only useful, but essential to many processes going on in life. With the knowledge of how to prevent the harmful bacteria from increasing where we do not want them, modern methods of surgery and hygiene have become very different from those of a hundred years ago, before Pasteur's discoveries.

Background reading

Preparing for a surgical operation

As soon as the doctor had gone Johnny felt better. The pain in his side had eased and the feeling of wanting to be sick had gone. The doctor had explained to his mother that he had an appendicitis, and would have to go into hospital to have an operation. This made him feel rather excited and important.

He wanted to sit up in the ambulance. Lying flat, as it lurched around corners, made his head swim. The hospital trolley was much smoother and quieter.

In the ward they lifted him onto a bed and he wriggled down into warm, clean smelling sheets.

A nurse counted his pulse rate and took his temperature. She recorded the results on a chart at the foot of his bed. Then the resident doctor came and talked to Johnny. He asked many questions about his symptoms. He listened to Johnny's chest and heart and felt his abdomen. The tender area now seemed to be in one place only – on the right side of his abdomen, low down. The doctor reported this to the chief surgeon; and Johnny was told that he would soon be taken to the operating theatre where his appendix would be removed.

A lady doctor put her head round the screens and smiled at him. She had a quiet voice and thin, strong hands. She was the anaesthetist and would be controlling Johnny's depth of sleep during the operation. She calculated the dose he would need of pain-relieving drugs and ordered a strange drug which would dry his mouth. This would prevent any saliva flowing down into his lungs while he was asleep. Normally, people cough up any saliva which gets into their windpipes, but Johnny's sleep was to be so deep that coughing had to be prevented. In the operating theatre the anaesthetist had a large trolley loaded with gas cylinders and numerous dials and flow regulators. Her control of the gases would be precise and accurate so that the depth of anaesthesia could be varied according to the surgeon's instructions.

The appendix is a short blind tube, about as long as the little finger, situated at the junction of the small and large intestine, but its functions are not precisely known. It can become inflamed due to infection by microbes but, fortunately, in Johnny's case there are no complications.

The success of the operation depends on many things. When Johnny's body is injured, it heals. When the skin is cut, a scar is formed; later, new skin will grow to replace the scar. Johnny's skin performs many important functions. It is used in temperature regulation; it allows Johnny to feel and it protects him. By covering his body it prevents the entry of harmful microbes, so that when his abdomen is opened by the surgeon, the hole in his skin must be protected.

Inside the operating theatre everything is thoroughly clean. The walls and floors are tiled and easy to wash. There are no ledges where dust can collect. The air is drawn in from outside through special filters and flows away from the theatre towards the rest of the hospital. Special extractor fans are turned on in the theatre during an operation. Contaminated air from the wards must never reach the theatre. When Johnny comes to the theatre his ward blankets and sheets are removed and left outside. All the dressings and sheets used during the operation have been sterilized beforehand in large autoclaves which work automatically. Within each package of dressings is a tiny indicator tube and when the temperature has become hot enough to kill any microbes present, the colour in the indicator tube changes.

Surgical instruments are also sterilized. Some materials such as plastic syringes can only be used once and are then discarded. They are usually sterilized in the factory where they are made and packed. Before starting the operation, the surgeon and his assistants wash and scrub their hands and arms thoroughly for five minutes. Then a nurse helps them into their sterilized gowns, gloves, and masks. These are drawn on carefully so that the outside, which may come into contact with Johnny, never touches anything but sterile materials and instruments until the operation is finished.

In a small room outside the theatre the lady anaesthetist talks to Johnny before he goes off to sleep. At first he can only hear the gentle hiss of the gas; then, before it gets louder, his eyes feel heavy. He strives to keep them open to watch what is going on around him, but soon he sinks into deep sleep.

They put him gently on the operating table. After that, the control of the operation is entirely in the hands of the surgeon. Of all the preparations for this operation, his have been the longest and most arduous. He is in command of a team of other doctors, anaesthetists, and nurses, and his word is law.

Before Johnny's skin is cut the surgeon paints a sterilizing dye over his abdomen. The body cavity is opened and the swollen, inflamed appendix found and withdrawn onto the surface. Ligatures are tied round its blood supply and opening; then the appendix is removed. The wound is now stitched up and the operation is over.

Johnny, back in bed again, can smell clean sheets once more. His tummy feels stiff and on the right there is a tiny bandage over a small scar. In a week, or even less, he will be walking about again.

Chapter 4

Man against disease

4.1 Microbes and disease

We have learnt that germs from someone suffering from a common cold can quickly be carried on droplets of moisture in the air, passing from that person to another. But how do we know that it is the germs which actually cause the cold?

Before going on to consider the prevention of disease and its cure, we must pause to consider what experimental evidence there is for the hypothesis that microbes do, in fact, cause disease. It would be difficult to perform a properly controlled experiment to show that a particular kind of bacterium does cause a particular disease. That would involve giving people diseases they would not have caught in the ordinary course of events. So we must study accounts of experiments done by other people.

It was Louis Pasteur once again who gave the answer. In 1866, he was asked to investigate a disease that was killing off so many silkworms in France that the silk industry nearly came to an end.

A 'silkworm' is the caterpillar (larva) of a moth (*Bombyx mori*) which, when it forms a chrysalis (pupa), spins around itself a delicate covering of long fine fibres to make a cocoon. To use the silk, the strands surrounding the cocoon are unwound and spun into silk thread.

Pasteur first examined under the microscope the ground-up bodies of silk moths which had died from the disease, and found bacteria, not present in healthy moths. Then he ground up eggs laid by infected moths. In these he also found bacteria of the same kind which were not present in the eggs laid by healthy moths. He infected healthy moths with some bacteria and they quickly showed signs of disease. Those not infected (the controls) remained healthy. This was conclusive proof of the connection between bacteria and silk moth disease and the experiment paved the way for the investigation of other illnesses.

As you can guess, Pasteur's findings, although of great interest to scientists, were not at all popular with the merchants who sold silkworm eggs. Before these discoveries it had not mattered to them whether the eggs they sold were contaminated with disease, but their customers now became suspicious. In order to keep their stocks free from bacteria, they were forced to use more careful and expensive methods of culture.

Here, then, is one example to show that microbes really do cause disease. It also shows how, given the right conditions, an experiment can be devised to test such a hypothesis. We must now go on to consider some problems connected with the cure of disease, particularly in man.

4.2 The prevention of disease

Pasteur had proved that bacteria could cause a disease. But the problem remained of how a disease could be prevented.

Nearly one hundred years previously an English country doctor Edward Jenner (1749–1823) noticed that anyone who had suffered from the illness cowpox did not catch smallpox which is a much more severe disease. Cowpox comes from handling cows and causes a rash of spots especially on the hands. It was quite a common thing in Jenner's time for girls who milked cows to catch cowpox and this probably gave him his bright idea. With a sterile needle he took a small amount of pus from the spots on the hand of an infected girl and transferred it to scratches made in the skin of an uninfected boy who soon got cowpox. In figure 23 you can see a picture of Jenner performing the operation.

But Jenner's experiment was only half done. The boy recovered from cowpox and two months later, taking a grave risk, Jenner injected into the boy's arm pus from the spots of someone suffering from smallpox. Luckily for Jenner, the boy did not contract smallpox.

Our modern word 'vaccination' comes from the Latin *vacca* which means a cow, and reminds us that in Jenner's first vaccination against smallpox, he used the microbes of cowpox, a similar but much less severe disease. As the caricature in figure 24 shows, the 'New Inoculation' caused a good deal of suspicion and doubt in Jenner's time.

It is possible that a hundred years later, Jenner's discoveries gave Pasteur the idea of trying out similar operations on cattle, using much more carefully controlled experiments.

In France at that time many cattle were suffering from anthrax, a serious disease from which many of them died. Pasteur made a careful study of anthrax, and noticed that some animals developed the disease much more severely than others. He decided to inject two cows with a strong dose of anthrax bacteria, expecting them to die, but to his astonishment neither of the cows got the disease. Later, he found out that both animals had already suffered from anthrax. Could it be that they were now *immune* to it or, in other words, protected against it in some way? Pasteur argued that if it were possible to give an animal a mild attack of a disease, this might be sufficient to prevent it getting the disease more severely later on.

One investigation led to another, and finally Pasteur succeeded in producing a weakened and harmless culture of anthrax bacteria with which he inoculated cattle and sheep. Animals which received

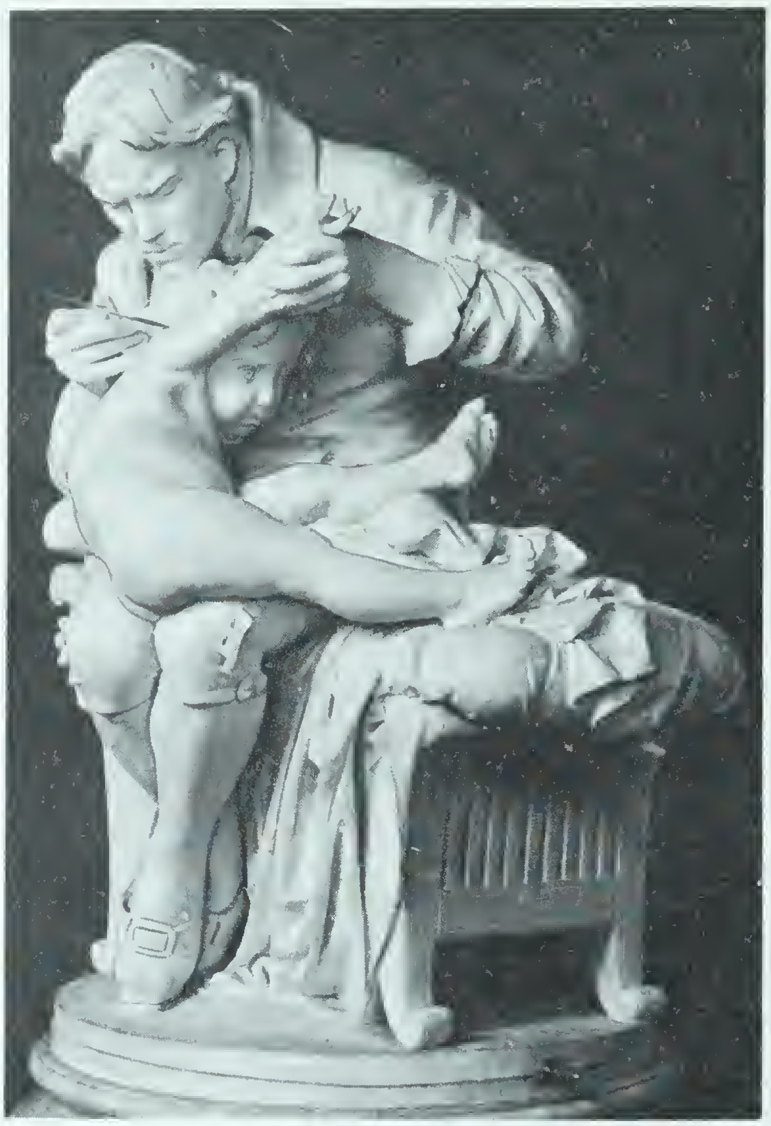


Figure 23
Statue of Edward Jenner (1749–1823). He is transferring matter from the hand of someone suffering from cowpox to scratches made on the skin of the boy.
Mansell Collection.

the inoculation were thus given a mild form of anthrax from which they quickly recovered. When the cattle and sheep were put with others which had anthrax in the severe form, they remained unaffected because they were immune.

Pasteur had learnt two things: that he could protect animals against a disease by injecting them with a weakened form of the organisms causing that disease, and that a particular inoculation would protect the animal against a single disease only, and no other.

It is worth stressing two things about Pasteur's methods of investigation which we have noted already: his insistence that scientific hypotheses must be founded on observation and that such hypotheses should be tested by experiments before any conclusions are drawn.

4.21 How our bodies react to infection

The boy that Edward Jenner vaccinated with cowpox had been made immune to smallpox. Nowadays most people are vaccinated against smallpox at least once during their lives. Many countries insist on visitors being vaccinated before they are allowed in.

When Pasteur inoculated the cow with weakened anthrax bacteria, he had no real knowledge of *how* the vaccine worked. We

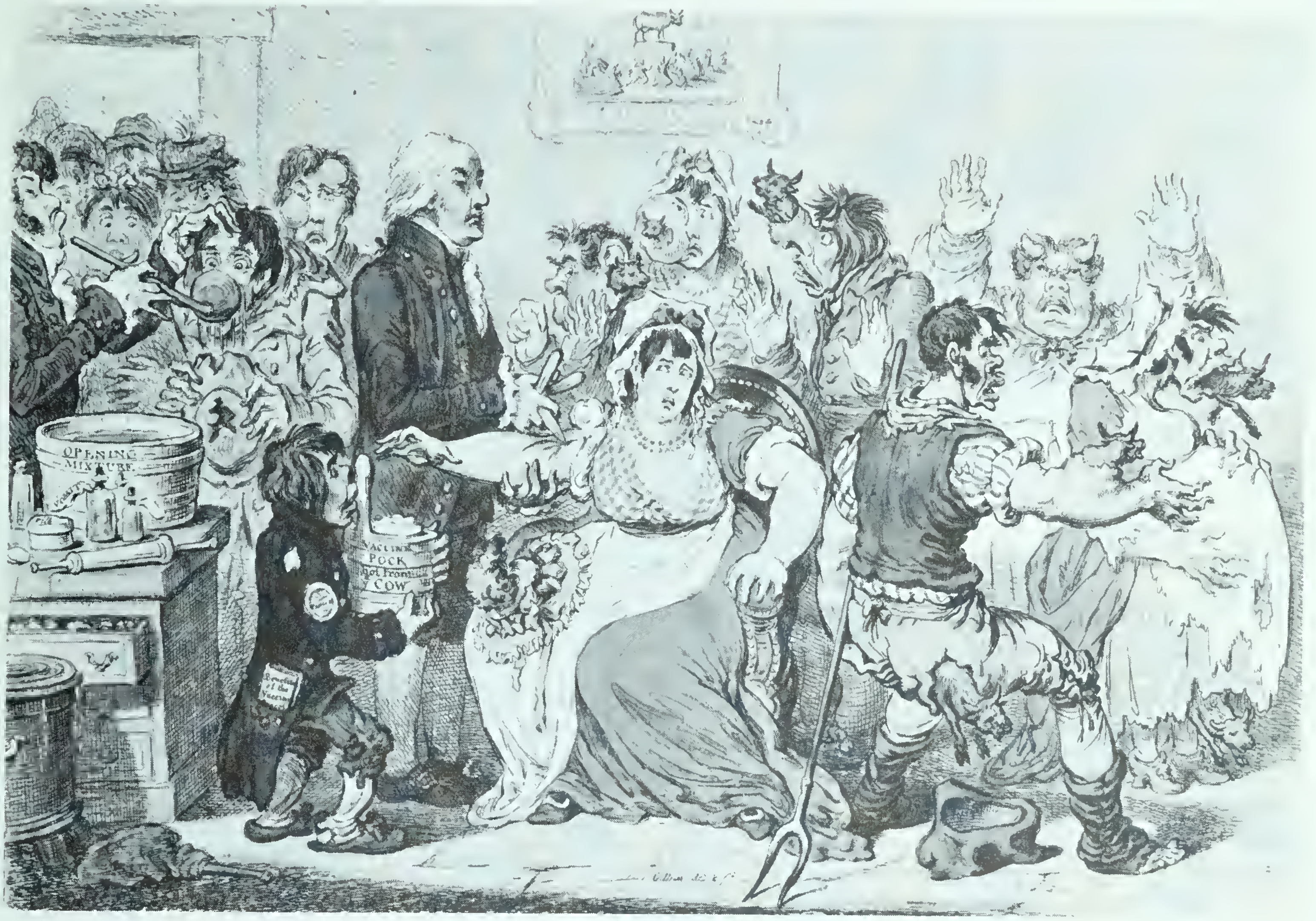

OPENING MIXTURE
VACCINE POCK hot from ye COW

Figure 24
'The Cow-Pock – or – the wonderful effects of the new inoculation'. From an etching by James Gillray (1757–1815), illustrating some of the absurd ideas held by the opponents of vaccinations. *Photo, Wellcome Historical Museum.*

now know that our bodies possess ways of attacking and repelling microbes; these are complicated processes which often take place in the blood by means of which microbes are carried from one part of the body to another.

Imagine that there are two armies fighting on opposite sides. The enemy troops are the invading microbes which cause the disease, while the defending troops are cells and chemicals inside our bodies, able to fight the invaders and destroy them. First of all, the enemy have to gain entry into the body, either through the nose, a cut in the skin, or in food. Once inside they meet the defence troops, and provided these are there in sufficient numbers and are strong, they will immediately attack and kill the invaders. Constant battles of this kind are waged in our bodies without our knowledge. If the enemy troops manage to get to the battlefield under favourable conditions they will multiply. The defence troops have got little chance against so many and may lose the battle if reinforcements do not arrive.

Vaccination is like injecting a few enemy soldiers which encourage the defence army to multiply. Should they now be faced with a large number of the enemy, they will be able to overcome them.

Of course it is not really as simple as this, but the important thing to remember is that if we keep our bodies healthy, and therefore able to build up a good defence (immunity), there is much less chance that we shall become ill.

4.22 Modern vaccines

Nowadays there are many kinds of vaccine which can be used to prevent a number of diseases. The Salk vaccine, first produced in the United States, gives us protection against poliomyelitis, a disease of the muscles and nerves which can cause paralysis. It is often combined with other vaccines such as those protecting against diphtheria, lock-jaw (tetanus) and whooping cough, so that only one injection is needed.

Figure 25 shows a culture of bacteria which cause diphtheria. This used to be a serious illness from which many people died. The chart in figure 26 shows how vaccination has enormously reduced the number of cases of diphtheria in this country. The height of each column represents the number of deaths from the disease each year. What conclusions can you draw from it?

4.3 The cure of disease

There are many different ways of killing bacteria, and we have come across several of them already. But the main problem in curing a disease is not only to find a means of destroying the micro-organisms but also to avoid killing or injuring the patient. In the Middle Ages the only way known of treating illness was to use various extracts of plants. Some of these had limited value but the great majority were probably almost useless. The first chemical to be used as a medicine to kill microbes (salvarsan) was invented as recently as 1910 by the great German biologist Paul Ehrlich (1854–1914).

During recent years, a whole new group of chemicals have been discovered which has changed completely our outlook on the cure of disease. These substances are all produced by various kinds of fungi and are known as *antibiotics* (from the Greek, *anti* = against; *bios* = life) – indicating that certain kinds of life cannot exist when they are present.

4.31 The discovery of penicillin

One of the most famous antibiotics is called penicillin and is made by the fungus *Penicillium*. Penicillin is so well known nowadays, that it seems strange to think that it is only a generation since Sir Alexander Fleming (1881–1955) first found that the *Penicillium* mould produces it. You can see a photograph of Fleming in figure 27. It often happens that scientists investigating one problem make an important discovery about something quite different. This is what happened in the case of penicillin. Fleming was one day examining a Petri dish in which he was growing bacteria and noticed that a mould had also grown in the dish. This must have settled on the culture while the lid was off, in much the

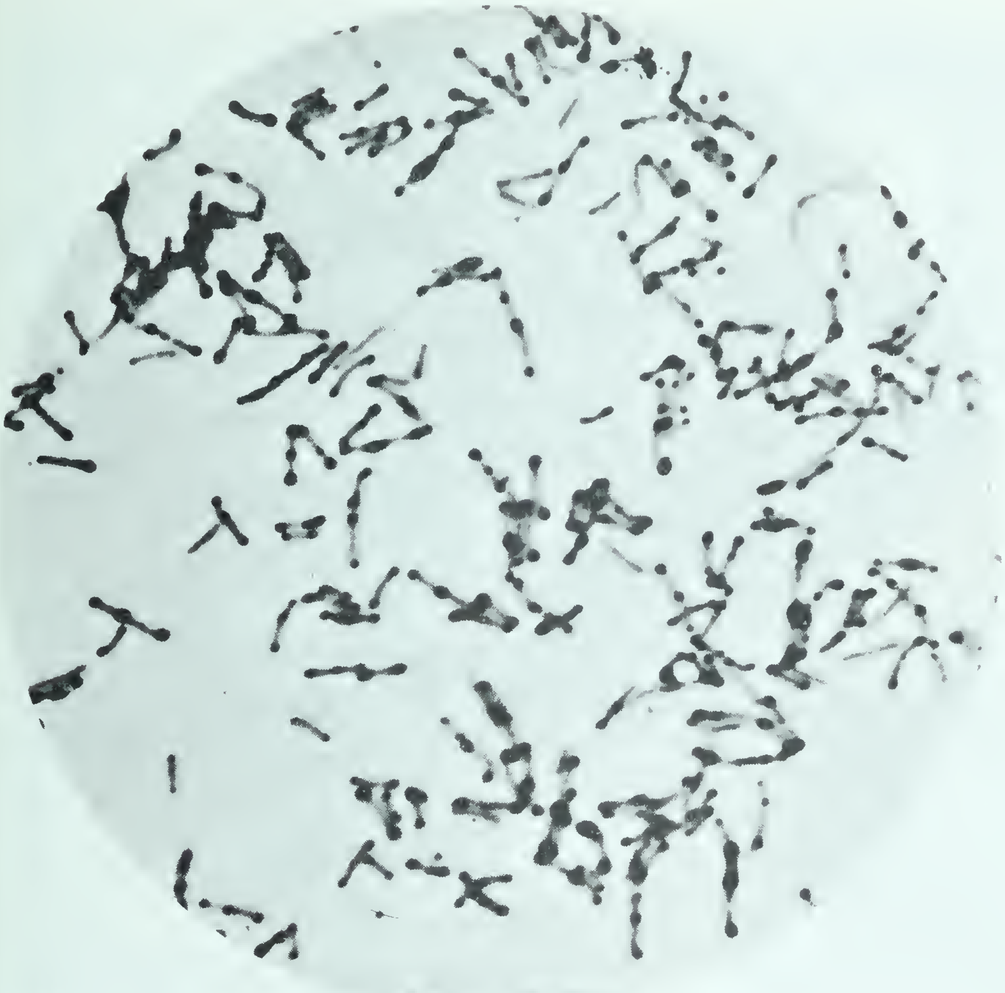


Figure 25
Culture of diphtheria bacteria, *Corynebacterium diphtheriae*, × 2,000. These are rod-shaped bacteria which cause inflammation of the tonsils, throat, and nose in patients suffering from diphtheria. They can be killed by injecting into the patients substances which have been taken from immunized animals. *Radio Times Hulton Picture Library.*

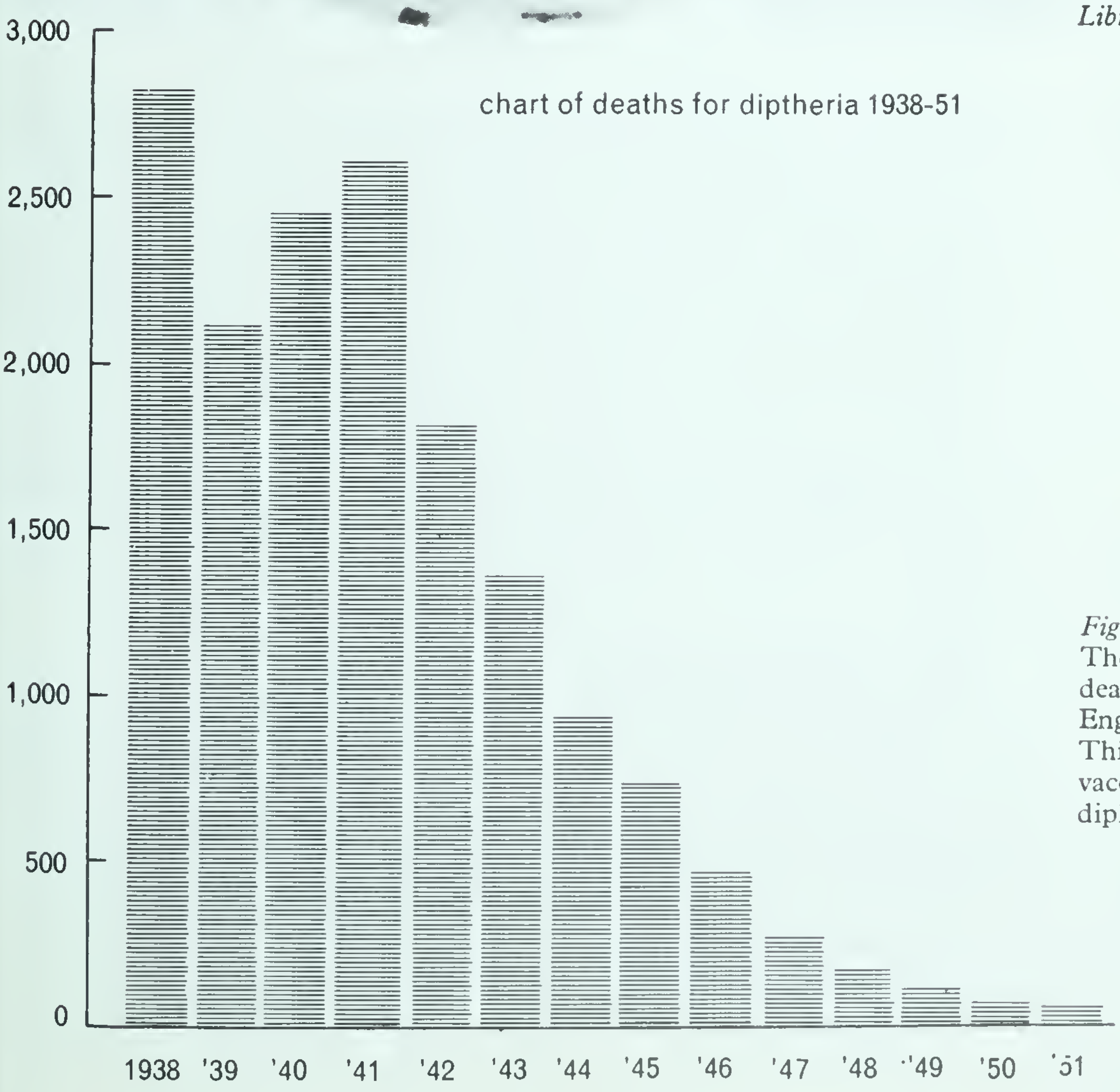


Figure 26
The effect of immunization on the death rate from diphtheria in England during the years 1938–54. This chart shows the importance of vaccinating people against diphtheria.

Figure 27
Sir Alexander Fleming (1881–1955) in his laboratory. He is holding a culture of *Penicillium* in a Petri dish.

same way as you probably found moulds growing in some of your cultures. But when Fleming looked more carefully, he found that there was a clear space round the mould where the colonies of bacteria had not grown. This gave him the idea that the mould must produce some kind of substance which stopped the colonies of bacteria from forming. Figure 28 shows the original plate of *Penicillium* which Fleming grew in 1928. However, our knowledge of chemistry at the time was not sufficiently good to enable Fleming to obtain the substance from the mould, and a few years went by before a team of scientists set to work and extracted a small amount of the valuable antibiotic, penicillin. Ways have now been found of growing *Penicillium* in vats and extracting penicillin on a large scale.

4.32 Growing *Penicillium*

Most of the organisms which produce antibiotics occur in the soil, where there are over one hundred different species of *Penicillium* alone. That usually used for the large scale production of penicillin is called *Penicillium chrysogenum*. It is grown in a liquid containing a mixture of sugar, mineral salts, and other substances to which are added small amounts of chemicals to encourage the more rapid production of penicillin by the fungus. Large amounts of the fungus are needed in order to produce a small quantity of penicillin.

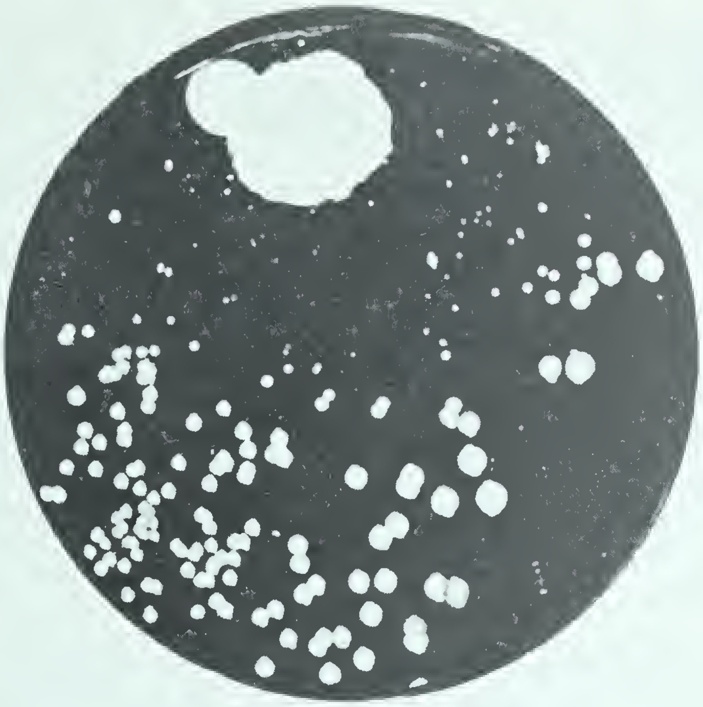


Figure 28
The original culture of *Penicillium* which Fleming made in 1928. Note the clear zones around the large white patch of mould where the colonies of bacteria cannot grow. *Reproduced from St Mary's Hospital Medical School pamphlet.*

You could grow some of the soil fungi on a special nutrient agar, containing malt extract, and see if you find *Penicillium* among them. *Penicillium* grows much more slowly than the other microscopic fungi and may be coloured red or yellow. The drawing in figure 29 shows what *Penicillium* looks like when it is magnified about 450 times.

4.33 Penicillin as an antibiotic

A hundred years ago Lister was still using carbolic acid as a disinfectant to prevent wounds from going septic (section 3.2). Nowadays we know that many of the bacteria causing the infection of wounds are killed if penicillin is used as an antibiotic. It is not effective against every sort of infection but kills most kinds of harmful bacteria. Moreover, penicillin possesses the other essential quality of a good disinfectant – it sterilizes the wound but does *not* prevent it from healing.

Since it is a powerful killer of bacteria and also harmless to most people, penicillin is also an invaluable medicine and can be used either as pills for the treatment of sore throats or injected into the blood stream to treat more serious infections.

The effect of penicillin on a culture of bacteria is most striking and illustrates beautifully the way in which an antibiotic works.

You can use a culture of *Bacillus subtilis*, a species of bacterium which grows quickly. The culture is poured onto sterilized agar in a Petri dish and then dried off in an incubator at 37°C for an hour or so. Small circles of paper, dipped in penicillin and called penicillin discs, are then placed on top of the culture. The strength of penicillin is always given in units: 5 units is fairly strong, but 2 units is weak.

You are provided with agar in a Petri dish which has received a culture of *Bacillus subtilis* in the way described above, together with a 5 unit and a 2 unit disc of penicillin.

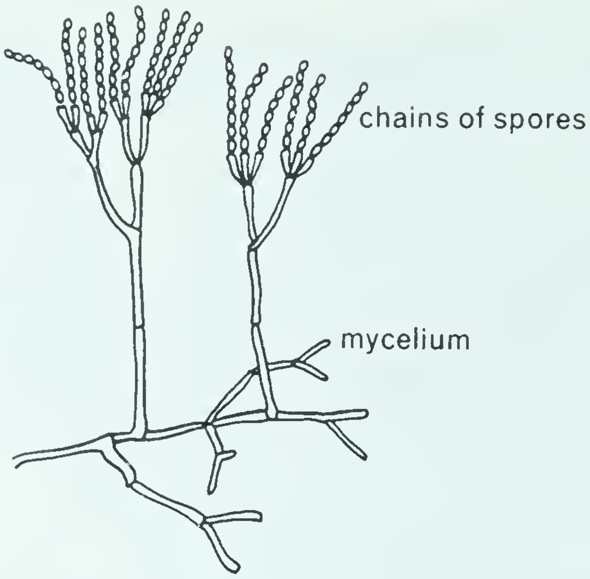


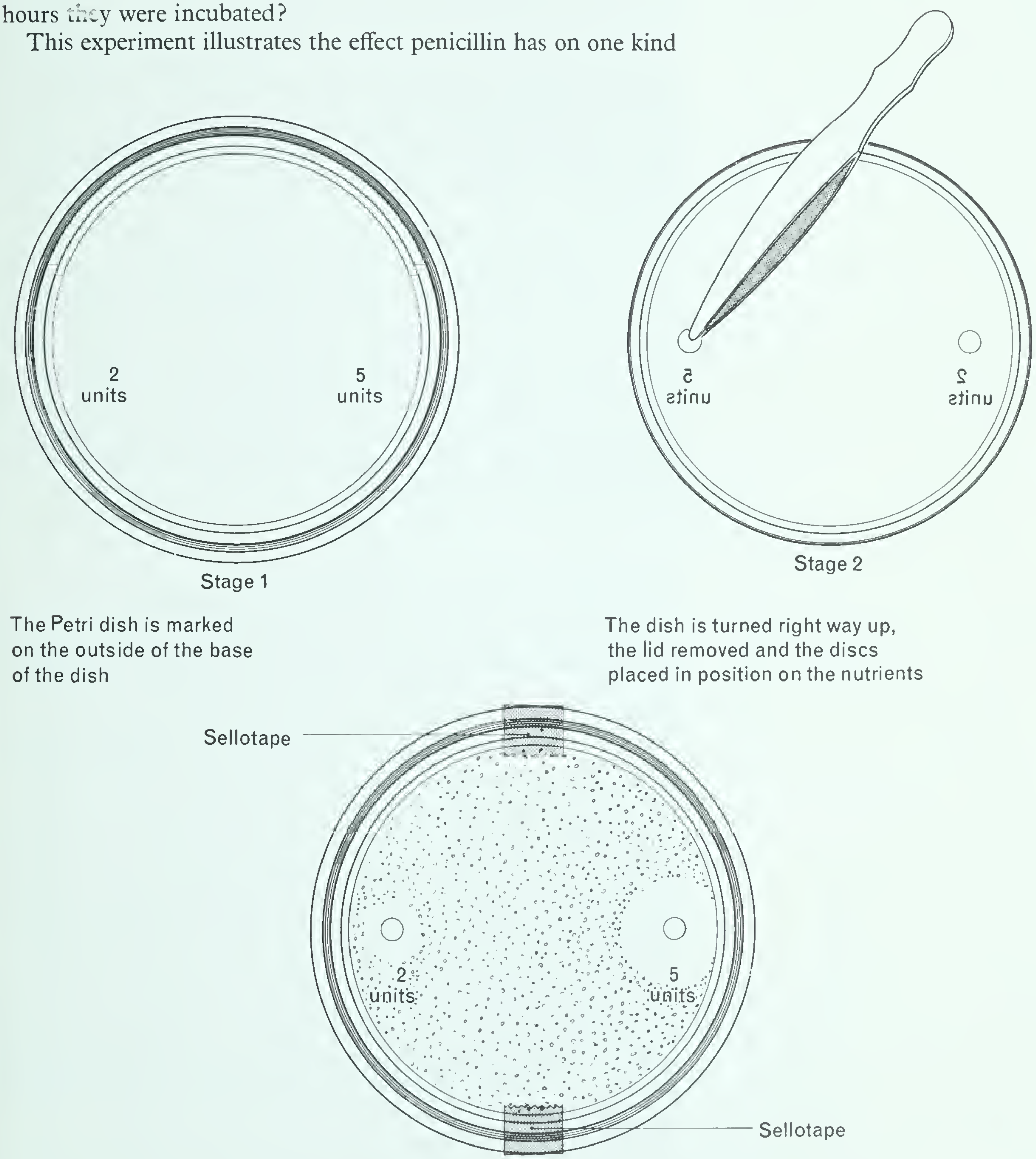
Figure 29
Penicillium mould × 300. The mould grows chains of spores which can be carried in the air or in the soil and can grow to form another mould.

1. Invert the Petri dish and on the *base* mark the position in which you will place the 5 unit disc and the 2 unit disc of penicillin (see figure 30, stage 1).
2. Turn the Petri dish the right way up again. You can see the marks you have made on the base of the dish because the agar is transparent.
3. Sterilize a pair of forceps by holding the points in a Bunsen burner flame for a second or two and then hold them away from the flame until they are cool.
4. With the sterilized forceps gently press a 5 unit penicillin disc on the agar, exactly over the place at which you made the 5 unit mark and the 2 unit disc over the 2 unit mark on the base of the plate (see figure 30, stage 2). Keep the writing on the discs uppermost.
5. Replace the lid as quickly as possible and attach it securely to the base in two places with Sellotape.
6. Put the dish in an incubator at 37°C.
7. After eighteen hours remove the dish from the incubator, turn it upside down and examine the colonies of bacteria that have grown. They should show through the transparent agar quite well.

Do the colonies come up to the edge of both the penicillin discs, or is there a clear ring where the bacteria have not grown? If so, can you offer any explanation for this? Is the clear ring larger around the 5 unit disc than around the 2 unit disc? Can you give a reason why this is so? The clear ring that you may have found around both of the penicillin discs is called the zone of inhibition. You could measure the size of the zone round each disc and record its radius in each case.
8. Using a ruler, measure, in millimetres, the diameter of the zone, and the diameter of the penicillin disc. Subtract the diameter of the disc from that of the zone (the radius is half this figure).

Compare your plate with others in the class. Do all the plates made by the class show the same growth of bacterial colonies, or do some plates show fewer colonies? Are the zones of inhibition around the discs the same size for each strength of penicillin? Can you suggest a reason why all the bacterial colonies on the plate were not destroyed by the penicillin in the discs during the eighteen hours they were incubated?

This experiment illustrates the effect penicillin has on one kind



Stage 1

The Petri dish is marked
on the outside of the base
of the dish

Stage 2

The dish is turned right way up,
the lid removed and the discs
placed in position on the nutrients

Stage 3

Does your culture of *Bacillus subtilis*
look like this after incubation?

Figure 30
Placing penicillin discs on a culture of *Bacillus subtilis*.

of bacterium, *Bacillus subtilis*, which is killed by penicillin. Suppose, however, you had used other kinds of bacteria. Your own noses contain different kinds and by swabbing your noses and culturing the bacteria on agar in the same way as you cultured *Bacillus subtilis*, you may be able to show that some bacteria do not behave in the same way because they are not killed by penicillin. These bacteria would grow right up to the penicillin discs on the plate, while others grown from the nose swabs would be killed. So you might have a zone of inhibition round the discs in which there were a few colonies of bacteria of a kind which penicillin cannot destroy.

Hospitals and laboratories make use of penicillin in the same way as you have been doing to find out what strength is needed to kill bacteria of different kinds. The penicillin diffuses out from the disc into the surrounding agar. As it diffuses further away from the disc, it becomes weaker and weaker. *Bacillus subtilis* is killed by a certain strength of penicillin, but when it becomes weaker than this strength, the bacteria are not killed and the colonies can grow. This explains why you may have found quite a large zone of inhibition around the 5 unit disc and a much smaller one around the 2 unit disc of penicillin.

4.34 Other kinds of antibiotics

Penicillin was the first antibiotic to be discovered and manufactured on a large scale, but in recent years the study of soil microbes has revealed others which can make antibiotic substances. One of these is streptomycin which has proved to be the most effective cure so far discovered for the disease tuberculosis.

There is no doubt that there are many more antibiotics still to be discovered and many of them may well prove to be valuable for curing infections which, at present, we cannot treat.

You may remember (see section 3·12) that there is one kind of bacterium, *Escherichia coli*, which is sometimes found in water and there is another bacterium, *Staphylococcus albus*, which is commonly found in our own noses. We could see if either of these bacteria is sensitive to the two antibiotics we have mentioned – penicillin and streptomycin.

Two plates have been inoculated – one with a culture of *Escherichia coli* and the other with a culture of *Staphylococcus albus*. A paper disc impregnated with penicillin and another with streptomycin have been placed on each of the plates which have been inoculated.

Examine the two plates carefully and see if you can answer these questions:

1. Is *Escherichia coli* resistant or non-resistant to (*a*) penicillin, and (*b*) streptomycin? How can you tell?
2. Is *Staphylococcus albus* resistant or non-resistant to (*a*) penicillin, and (*b*) streptomycin? How can you tell?

Summary

Although Pasteur laid the foundation of our modern knowledge of microbes, we must remember that Robert Koch made it possible for scientists to perfect techniques for isolating and growing bacteria. These were essential in order to discover the causes of different kinds of disease. Our modern system of vaccination, founded upon Jenner's primitive methods, has been so improved that it ensures immunity from many of the more serious illnesses. More than this, we have harnessed to our use some of the microorganisms themselves, extracting from them antibiotics with which we can destroy the others.

Background reading

The miracle drug

Throughout history, men have dreamed of miracle drugs which one day would provide cures to all human illness. Until the beginning of this century, the search for such medicines was confined mostly to the extracts of plants. Then, in 1910, the great German chemist Paul Ehrlich made a discovery which opened up a completely new field. He invented salvarsan – the first chemical to be used as a cure for human disease.

Twenty-seven years later (in 1928) another discovery was made by Professor Alexander Fleming (who became Sir Alexander Fleming) which, in many ways, has proved to be as important and far-reaching as that of Ehrlich before him. Fleming was studying bacteria (*Staphylococci* – the kind of germs that cause boils and sore throats). He was examining some old bacterial plates (in Petri dishes similar to the ones you have prepared) when he realized that a mould (fungus) had grown on one of the cultures. There was nothing unusual about this, but Fleming also noticed a very odd thing – the colonies of staphylococci growing near the mould seemed to have disappeared. It looked as if some substance being produced by the fungus had destroyed the bacteria. So he cultured the mould, growing it in broth, and also carefully preserved the original plate. To his surprise he found that substances in the broth where the fungus was growing had the power of destroying a number of different bacteria all of which cause human diseases. Further, it was effective even when diluted many times. The mould was later identified as *Penicillium notatum*, and the mysterious substance which it had produced was called 'penicillin'.

Fleming injected large doses of broth containing penicillin into mice and showed that it was not harmful. But while doing these experiments he also found that the broth lost its power of killing bacteria if kept for any length of time. Penicillin seemed to be a substance which was difficult to preserve. Perhaps it decomposed when kept in laboratory conditions?

Curiously enough there was little interest in the first reports on penicillin. Scientists were busy thinking of other ways of curing human disease. Then, in 1938, H. W. Florey (now Lord Florey) and E. B. Chain started work at Oxford on a study of substances produced by living things and that help to kill the harmful bacteria which attack them. On reading through the literature Chain came across Fleming's account of penicillin, and decided to repeat his experiments. Everything he had described turned out to be true, including the difficulty of preserving penicillin in the laboratory.

Now Chain took the experiments a step further and injected different kinds of harmful bacteria (e.g. *Staphylococci* and *Streptococci*) into separate groups of mice. Each group was divided in two. One-half also received a dose of penicillin broth, the other (the control) did not. What would happen to the diseased animals? It was an exciting moment and the scientists stayed up all night in the hope of finding the answer. The experiment was a complete success – the untreated mice died while those that had received penicillin survived. But the problem remained of isolating and preserving this new 'miracle drug'.

It was now June 1940 and wartime. England was awaiting invasion. Fearing that Fleming's precious cultures of *Penicillium* might be lost if the Germans landed, the scientists soaked the linings of their coats with broth containing the mould, so that if only one person survived the culture could be grown again. (The spores of many fungi can remain alive in a dried state for long periods of time.) At this time there was an urgent need for drugs to cure infected wounds and other diseases. Florey realized that in spite of all the hard work at Oxford it was going to take many months to obtain pure penicillin even in small quantities owing to the complex processes needed in extraction. So, in 1941, Florey flew to the United States taking supplies of the cultures with him. There he joined a group of American scientists working at the Northern Regional Research Laboratory, Illinois.

The search for a way of isolating penicillin now started on a big scale. Soon it was discovered that the yield of the new drug could be increased by twenty times if the *Penicillium* was grown in corn-steep liquor (the liquid left behind after maize has been soaked in water before being ground into flour). Meanwhile many other strains of the fungus from different parts of the world were examined to see if they would give larger amounts of penicillin. Strangely enough, one of the best was found on the scientists' own doorstep – growing on a mouldy melon obtained from the local market.

Eventually a way was found of making and preserving pure penicillin and several manufacturers began to make it commercially. By this time trials with many animals and different kinds of dangerous bacteria had confirmed the value of penicillin. It was indeed a miracle drug.

For the part they had played in the development of penicillin, Fleming, Florey, and Chain together received the Nobel Prize for medicine in 1945. Since then numerous other antibiotic substances similar to penicillin have been discovered. One of the best known is streptomycin which has proved successful in the cure of tuberculosis. All are produced by different kinds of fungi and act by killing other living organisms, particularly bacteria, which come in contact with them.

Chapter 5

Shapes, sizes, and movement

5.1 The importance of size and shape

By now you will probably have some idea of the wide range of sizes and shapes to be found in living organisms. Plants range from trees to bushes, to small herbs, to tiny algae. Among animals there are vertebrates, insects, worms, and jellyfish to mention just a few. Among the plants we find at one end of the scale the Californian redwood – a tree which can grow to a height of 272 feet, weigh about 6,000 tons and which may live for more than 3,000 years. At the other extreme are bacteria with a diameter of one five-hundredth of a millimetre or less and weighing roughly 10^{-8} g. Similarly, among the animals the largest living animal, and the longest that has ever lived, is the blue whale. It may be as long as 100 feet and weigh about 120 tons. But an amoeba is only about $\frac{1}{4}$ mm across, and weighs less than a hundredth of a gram.

You may have heard of the extinct giant reptiles called dinosaurs that lived 300,000,000 years ago. The largest of them was only a quarter the size of a fully grown blue whale, which is about forty times heavier than an adult elephant.

Think of the differences between animals and plants, and between land animals and sea animals. Can you make a list of the reasons why it is possible for water animals to be larger than those that move about on land? And why is it possible for a tree to be so much larger than the largest animal?

Clearly, the size of an animal or plant has something to do with the strength of the material of which it is made. Most plants or animals, whatever their size, are strong enough to withstand the normal conditions in which they live. But a tree can be blown down in a gale, and an animal can break a bone if it is subjected to greater stress than usual.

5.11 Size and support

If we had unlimited time and opportunity it might be possible to test the relationship between support and weight in many different plants and animals. You would take each in turn, measure the dimensions of the parts which support it, weigh it, and then increase its weight artificially until it collapsed. However, this would be a laborious and not very practical experiment; also it would be cruel to the animals. By using Plasticine, we can demonstrate the relationship between size and support.

1. Make a cube of Plasticine measuring 1 cm along each edge and another one 2 cm along each edge. These measurements are called the linear dimensions.

2. Collect all the 1 cm cubes together and weigh them.

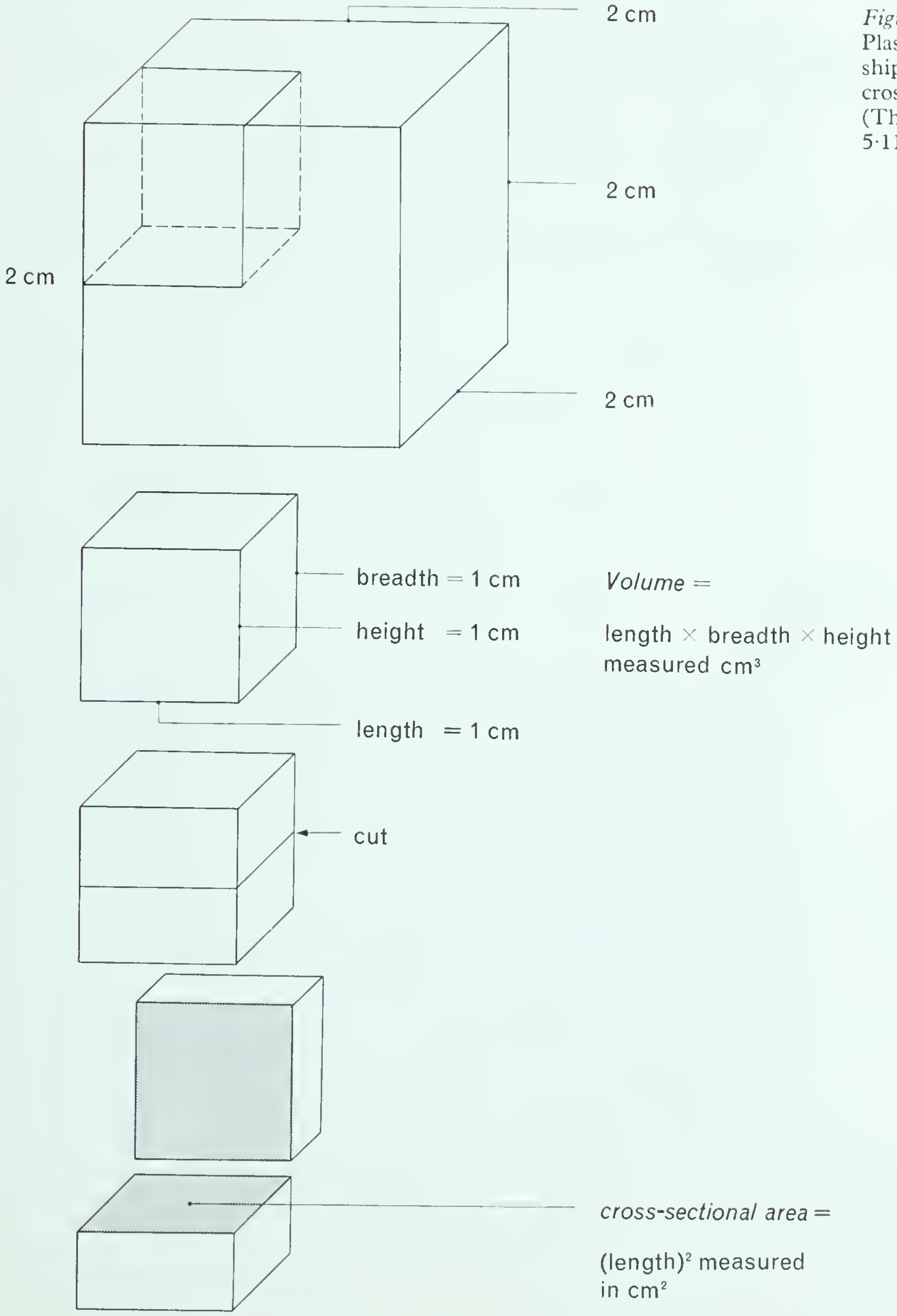


Figure 31
Plasticine models to show relationship between linear dimensions, cross-sectional area and volume. (The weight measured in section 5·11 is proportional to volume.)

3. Now find the average weight of each cube by dividing the total weight of all cubes by their number.

4. Find the average weight of the 2 cm cubes by collecting all these together and weighing them.

Knowing these two average weights, can you say how many times heavier the second cube is than the first (figure 31)? Remember that the dimensions of the second cube are twice those of the first.

The part of the cube which supports it on the table and resists squashing from above is known as its cross-sectional area. This is the area of any one of its faces. You can find the relationship between the cross-sectional area of the 1 cm cube and the 2 cm cube by seeing how many times the outline of the smaller one will fit on to that of the larger. How many times will it fit? You can produce a working rule for this relationship between linear dimensions and cross-sectional area by repeating this experiment with cubes of 3 cm and 4 cm sides and seeing how many times the outline of the 1 cm one will fit onto each. Set out your results in table form and at the same time record the weights of the cubes.

Length of side (cm)	1	2	3	4
Times C.S.A. is larger				
Weight (g)				

Table 1.

Look at a number of common animals such as dogs, cats, sheep, and cows and compare them with drawings of some less common animals which you may have seen in a zoo (see figure 32). How does the thickness of the leg in each animal compare with, say, its height?

Let us find out something more about the way in which an animal supports its weight.

Imagine that the leg of an animal or the trunk of a tree is made of Plasticine. When you work Plasticine with your hands it begins to squash as you squeeze it between your fingers. In this experiment, we want to measure the pressure that will *just* squash pieces of well-softened Plasticine. Instead of cubes you can make rods. The *cross-sectional area* of the rods will increase with their diameter – the length across the middle of the circle. Compare your results with what you found for the cube. As the diameter doubles, the cross-sectional area becomes four times as great. Record the diameter (in inches or centimetres) of each size of Plasticine rod on the top line of the table as in table 2.

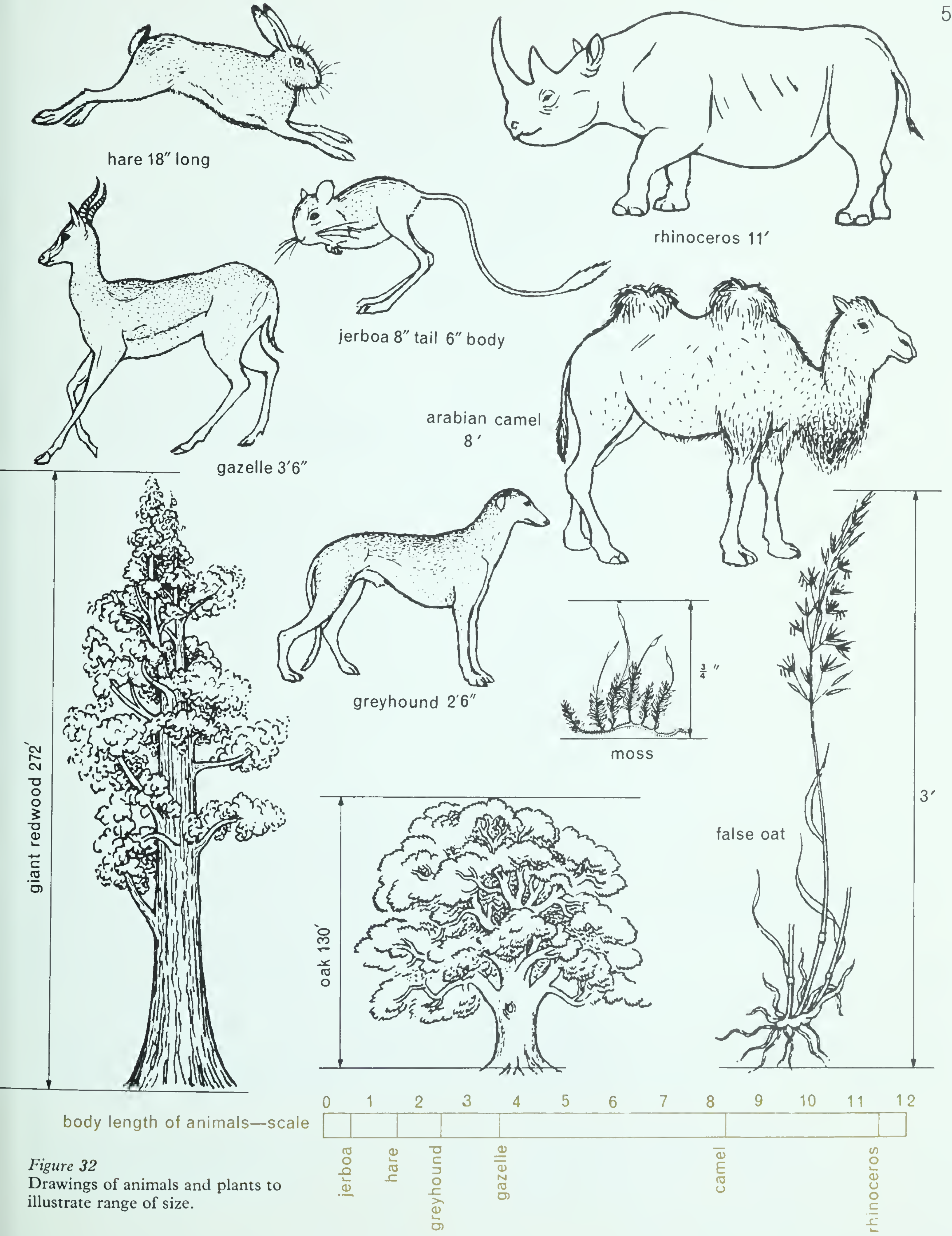


Figure 32
Drawings of animals and plants to illustrate range of size.

Linear dimensions	diam (cm)	0·5	1·0	2·0
	length (cm)	2	4	8
Weight (pressure) supported (g)	1st			
	2nd			
	3rd			
	4th			
	Average			

Table 2.

To measure the least force required to squash the rod, stand the model on the pan of a spring balance or kitchen scale (figure 33).

1. Press the top of the Plasticine rod gently with a piece of dowel or wood.
2. Increase the force gradually.
3. When the Plasticine just begins to give, record the reading of the scale.
4. To make sure you always apply the same amount of squashing, use a collar or tube as a gauge.
5. Roll out the Plasticine to its first diameter using a ruler or board and two dowels (see figure 34).
6. Repeat several times for this thickness.
7. Repeat the experiment for each different thickness of Plasticine rod.

Your results will vary slightly depending on when you decide that the Plasticine starts to give and also on when you feel it has reached the height of the collar. It is therefore better to repeat the experiment several times with each thickness of Plasticine and to take the average of the readings. Compare these results with those in table 1. You have already learnt that the weight of an object increases eight times when the linear dimensions are doubled. Does this last experiment show that when the linear dimensions are doubled the model will support eight times the weight?

Because the strength of bones or wood does not alter, the supporting power can only be increased by increasing their cross-sectional area. Think of the crushing which the bone in the leg of an elephant has to withstand when the weight of the animal is supported. What would happen to the leg bone if an elephant were to double its size? The crushing of the material of the limbs is one of the things which makes it impossible for animals to grow beyond a certain point.

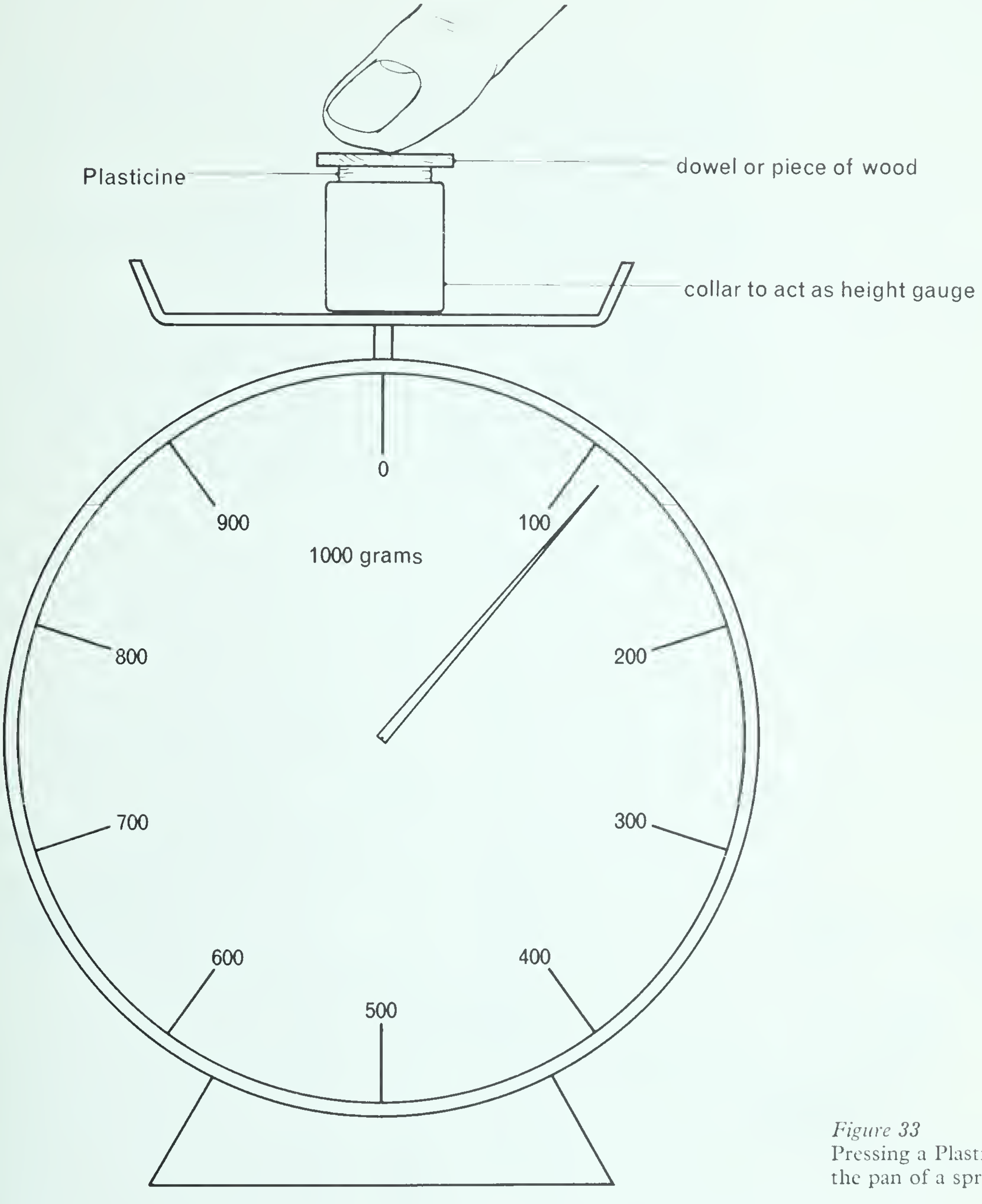


Figure 33
Pressing a Plasticine cylinder on the pan of a spring balance.

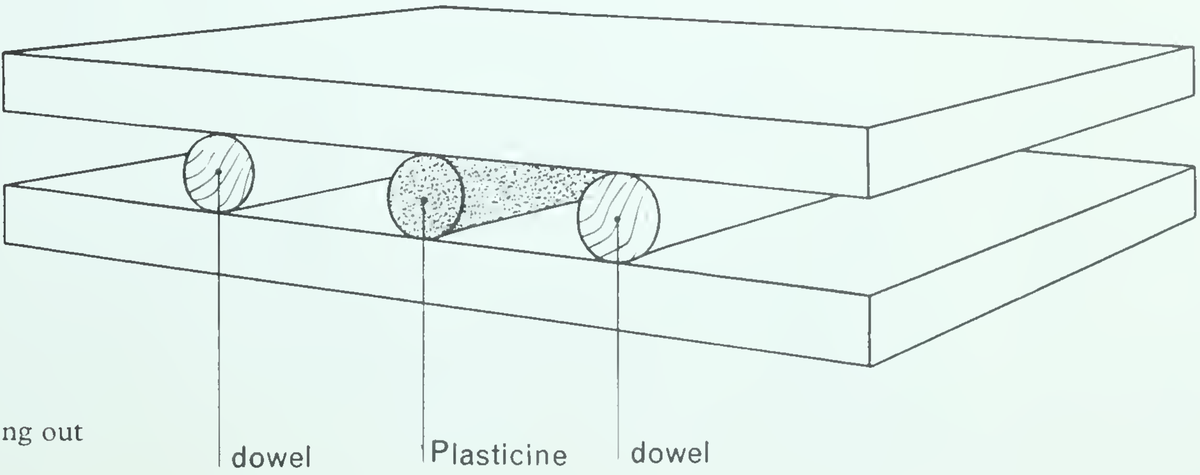


Figure 34
Boards and dowels for rolling out Plasticine cylinders.

5.12 Strength and length

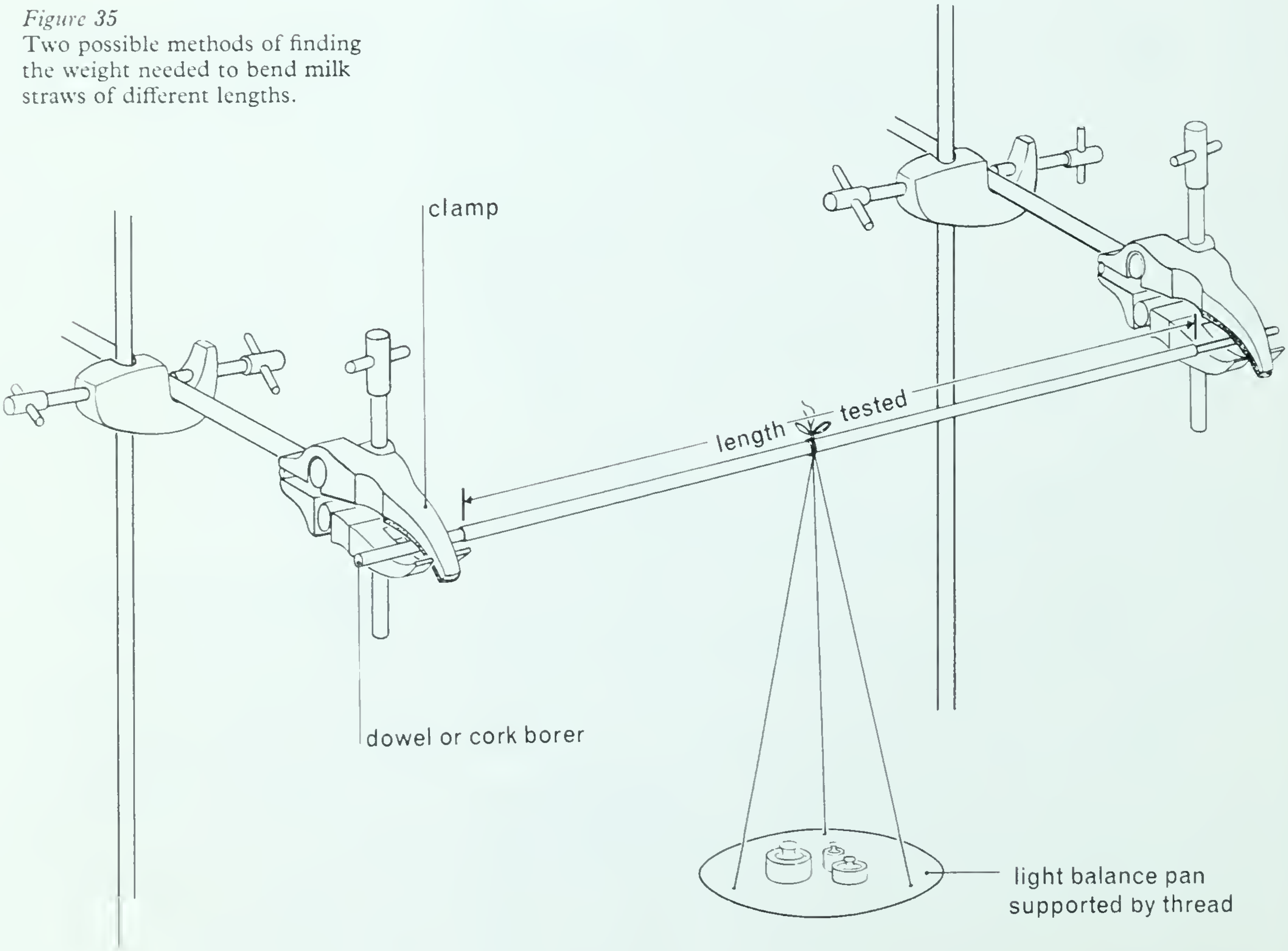
When animals move and when plants are blown about by the wind, there are strains other than those from above. What additional danger of breaking is there in the leg of an animal such as a giraffe, or in a tall plant such as a tree?

We must set out to find the effect of increasing the length of bones. In this experiment we will increase the length without altering the cross-sectional area so as to keep the experiment simple.

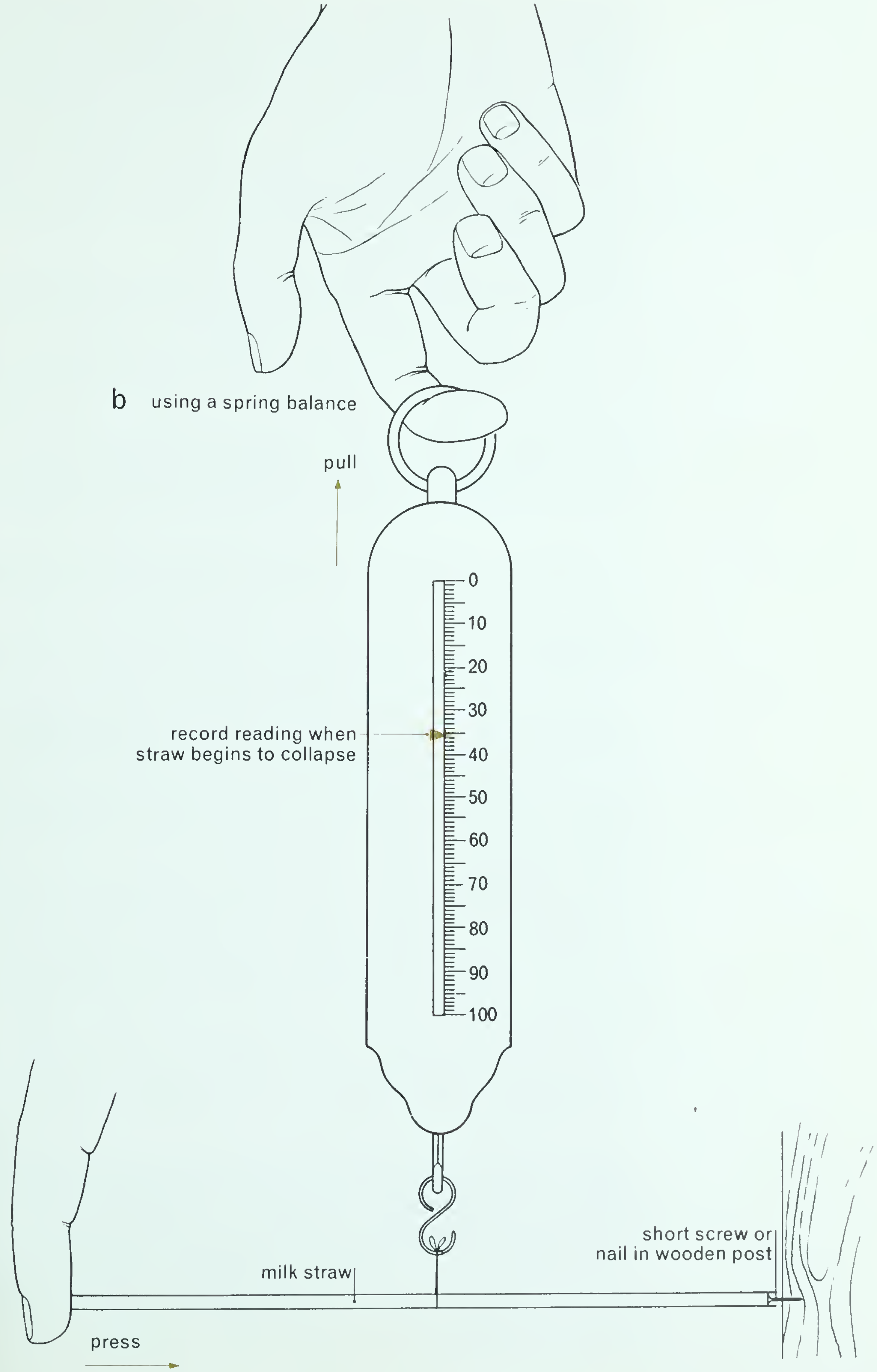
Long sticks break more easily than short sticks of the same thickness. How does the length of animals' legs compare with the size of their bodies? Compare a giraffe, an elephant, and a horse. Can we find out what length of leg will support any particular bulk?

An experiment can easily be done using milk straws.

Figure 35
Two possible methods of finding the weight needed to bend milk straws of different lengths.



a using a pan and weights



b using a spring balance

pull
0
10
20
30
40
50
60
70
80
90
100
record reading when straw begins to collapse
short screw or nail in wooden post
milk straw
press

1. Prepare a number of milk straws without cracks in them so that you have full length straws, half straws, and quarter straws.
2. Take a whole straw and support it by two pieces of dowel with nails in one end. The dowels should be fixed in clamps so that 16 cm of straw is left between them.
3. Using a spring balance, find the pull needed to break the straw (figure 35*b*) or hang a balance pan supported by thread at the centre of the straw and load this pan with weights as shown in figure 35*a* until the straw collapses.
4. Record the weight which causes the collapse.
5. Repeat the experiment with the other two lengths of straw and enter your results in a table similar to table 3.

Length of straw (cm)	16	8	4	2
Reading on balance (g)				

Table 3.

Can you work out the relationship between length and ability to support different weights?

5.13 Bones

So far, we have been trying to find out what limits the support provided by the materials of which plants and animals are made. If you look at the leg of a large animal, you will see that it is made up of a number of different materials, all of which help to provide support. The most important of these is bone. We shall now compare the bones from animals of various sizes.

You can collect leg bones from chickens or rabbits that you have eaten at home. Bones of larger animals, such as a bullock, a sheep, and a pig, can be got from your butcher. In order to compare these, you should always use similar bones – either the upper leg bone (*femur*) or the shin bone (*tibia*). The tibia of a chicken is the bone known as the drumstick.

1. Take the femur of a bullock and a chicken and saw them across.
2. Measure the area of each.
3. You can now relate this to the weight the bone has to support.

An average bullock weighs between 800 and 1,200 lb, so that each leg, when the animal is standing still, must support a minimum of 200 lb. An average chicken weighs 5 lb, so that the weight on each leg, when the animal is standing still, will be 2½ lb.

The weight on the leg of an animal increases considerably when the animal starts to move. As its position alters, additional and more complex strains arise. For the moment we shall only consider stationary animals.

As you will have seen in the last experiment (section 5.12) the strength of a support is influenced not only by the cross-sectional area, but also by its length. So you must now measure the length of the two bones as well as the cross-sectional area. Set your results out in a table as in table 4.

	Bullock	Chicken
C.S.A. of femur		
Length of femur		
Weight supported	200 lb	2·5 lb

Table 4.

How many times larger is the cross-sectional area of the bullock's bone than that of the chicken? Is the increase in length proportional to this or not?

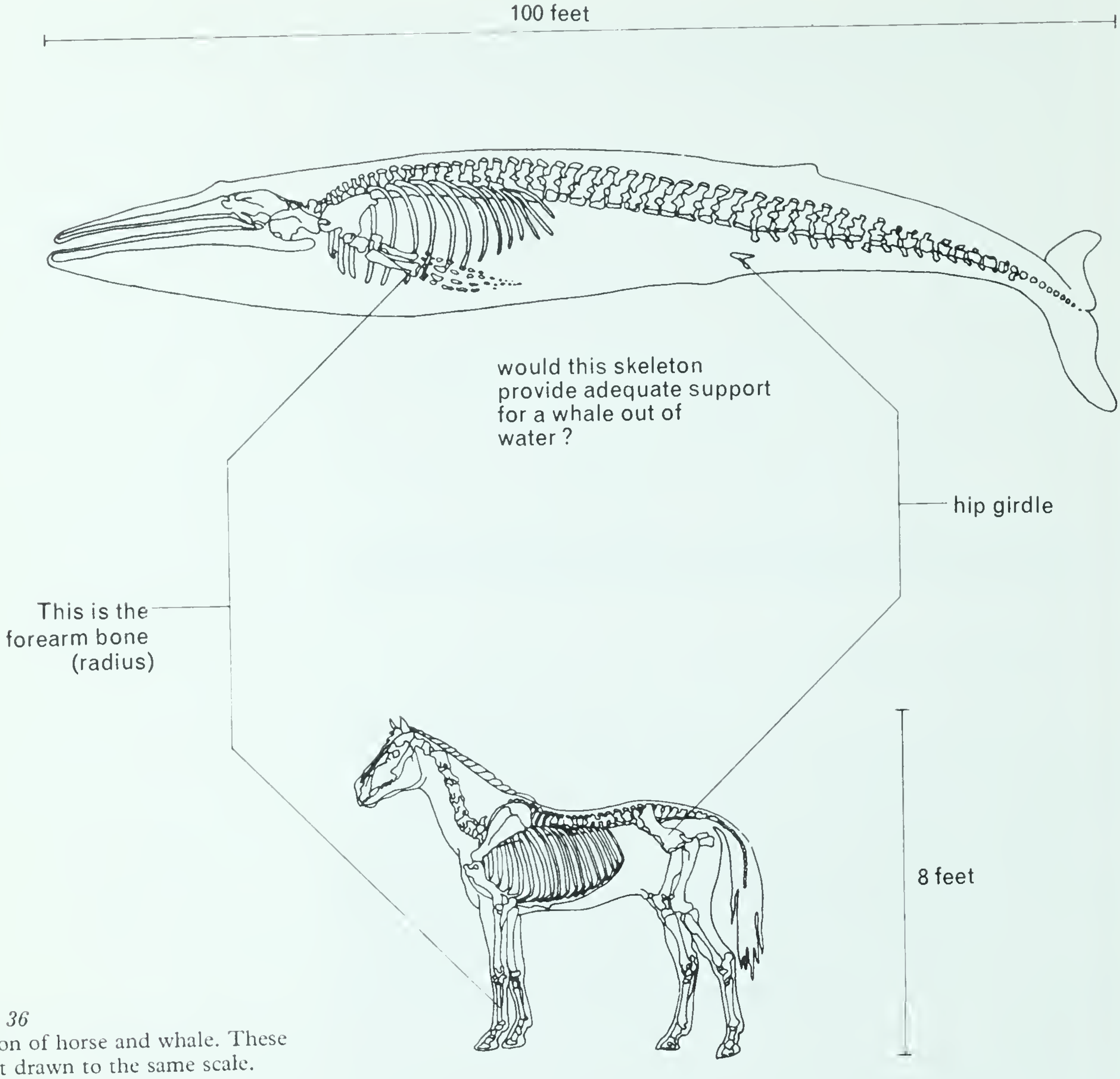
5.14 Weight in water

We learned earlier (section 5.1) that the largest animals live in the sea. The blue whale is the largest animal alive and can be 100 feet long or more. It lives in most of the seas of the world but is becoming rare because of hunting.

But why are whales able to grow bigger than land animals? You will probably have experienced the sensation of being lifted up when you swim in the sea. And you may have felt with your hands how much easier it is to lift a stone from the bed of a stream when the stone is beneath the surface, and has not been lifted above it. This apparent loss of weight is caused by the up-thrust of the water and is called buoyancy.

Because of the support due to buoyancy, animals and plants that live in the water do not need to have such strong support of their own. Look at the plants in a pond or an aquarium and see what happens to them when you move them with a stick. Now remove a handful of water plants from the water. What happens to them as they leave the water? How do the length and thickness of their stems and the size of their leaves compare with those of land plants of a similar size? Compare Canadian pond weed with a spray of privet.

If you examine the skeleton of a whale and that of a horse (figure 36) you will see that one is built to be flexible and the other to form a firm supporting frame. If the whale is stranded out of the water it is quite unable to support itself; it will be killed because its own weight will crush its vital organs.



would this skeleton provide adequate support for a whale out of water ?

Figure 36
Skeleton of horse and whale. These are not drawn to the same scale.

Compare the proportions of the front leg bones. Why does the horse have bones which are much thicker in proportion to its size?

5.15 Smallness

We shall be concerned later, in Chapters 6 and 7, with what limits the size of animals and plants. To make a beginning, try using any books of reference that you can find.

Look for the smallest –

1. Mammal in this country
2. Bird (*a*) in this country, (*b*) in the world
3. Flowering plant you know
4. Animal of any sort
5. Green plant
6. Living object (some of the smallest living things are neither plant nor animal).

5.16 The chessboard of life

To summarize what you have learnt so far about size, construct a chessboard of life for yourself.

This is a reminder of an old trick, passed on in a legend about a man called Sissa in India. It is to persuade someone to put one object on the first square of a chessboard, two on the second square, four on the third square, and to continue doubling the number of objects on the different squares until the sixty-fourth square. Sissa, who was an adviser to a king and very interested in chess problems, easily obtained the promise of a grain of wheat on the first square and a doubling of the number on each successive square. Try it on your father with pennies! The king soon realized that there was not enough wheat in the world to put the promised number of grains on square 64. You would be the richest person in the world if your father could carry out his promise with pennies.

We can use the same idea to show the great variation in the size of living things. Since we are more familiar with large plants and animals, we can start with the largest instead of the smallest and work downwards through the squares, halving the weight each time we move from one square to the next. To save using numbers that are too large to write easily, it is a good idea to change units at convenient places. Start by using weights in tons, then change to hundredweights and eventually to pounds and to ounces. When you reach an animal about the size of a mouse, weighing an ounce or so, you can change over to grams and then to milligrams.

1 oz = 28 g = 28,000 mg

The blue whale will occupy square one of your chessboard at over 100 tons. The next square, 50 tons, can be filled by another whale and the third, at 25 tons, still requires a whale. (If you include creatures that are extinct, the second square could also be filled by the largest known dinosaur.) The largest elephant does not quite reach the weight for square four, which again has to be filled by a whale. Square five takes the biggest shark, or an elephant of average size.

On which squares would a man of 180 lb and a mouse of 28 g stand?

The animal on square 64 will of course be very small. But even so, there are many living things too small to go on to the chessboard.

If you included plants in constructing the chessboard, the first five squares would all be occupied by trees, and the blue whale would come on only at square six.

5.2 Shapes of living things

Living things differ greatly not only in size but also in shape. You saw in figure 36 the difference in shape between the skeleton of a horse and a whale. This difference is partly connected with the fact that horses and whales live in different environments. We can

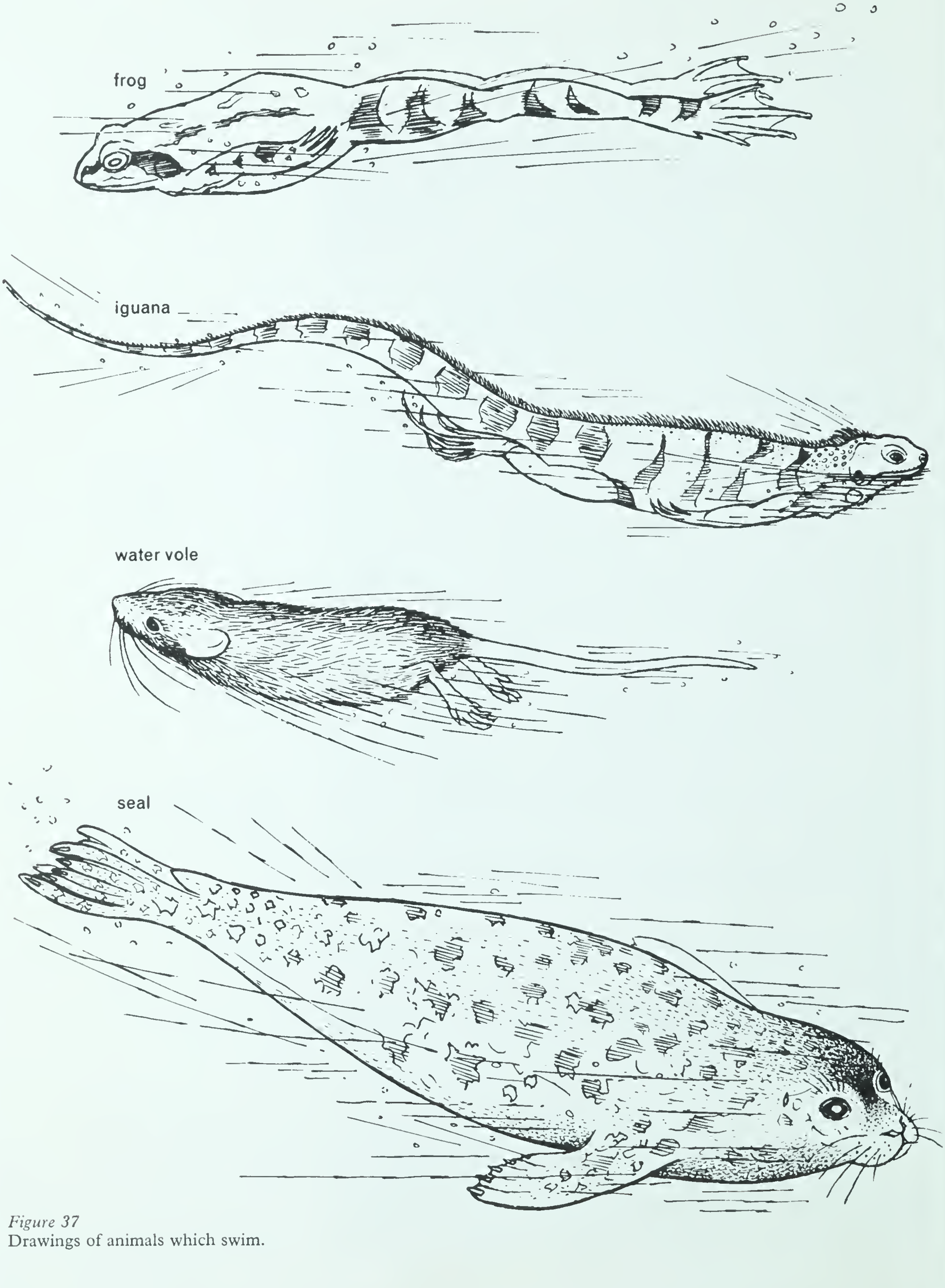


Figure 37
Drawings of animals which swim.

now look at the shapes of a variety of organisms and see how these can help the animals and plants in their everyday lives.

5.21 The streamlined form

Animals must be able to support themselves and also move about in the kind of surroundings in which they live. The whale not only cannot move on land but dies when it is taken from the water. And yet it lives and moves about perfectly supported in the sea.

If we look at the shape of animals that live in water we find a similarity among those that move quickly and those that maintain their position in fast moving water. They are all streamlined or torpedo-shaped (see figures 37 and 39).

If you try running in water you will soon realize why your shape, in its normal, upright position, is not suited to this. For water resists movement by pressing against objects passing through it, in the same way as it supports things that float. It seems that it will press with a greater force on a sheet of metal a foot square than on the point of a pencil.

You can test this by throwing a bucket, with a rope tied to the handle, into a pond and pulling it in. Now repeat the experiment using a plank of wood the same weight as the bucket, with a rope tied to one end.

Which is the harder to pull though the water?

If you can get to a swimming pool, try having a race between a bucket on the end of a rope and one of your friends grasping a rope with his arms stretched out in front, in line with his body and legs. Pull both across the bath as quickly as possible. What steps should you take to see that this trial of strength will tell you what you want to know even if one puller is stronger than the other?

If you now ask the person being towed by the rope to 'bunch-up' by putting his arms around his knees, do you find it easier or harder to pull him across the pool?

The resistance of air is far less than that of water, and hardly affects normal movement on land. You are not aware of pushing against the air when you move around, except perhaps when there is a strong wind blowing. However, animals that move fast, and particularly those that fly, are affected by the pressure of the air. How do the shapes of birds and flying insects compare with those of fish?

When men first made fast-moving objects, such as boats, cars, and aircraft, they did not always remember that they would have to face the same problems as do living things when they move quickly in water or through the air. The first boats and cars were solid and cumbersome, based on the idea that strength was the most important factor. However, when men tried to increase the speeds of these machines they came across unexpected difficulties. Speeds did not seem to increase as easily as they should and the structures showed unexpected stress and strain.

Designers first thought that the most important part of a moving object was the front which, they believed, should be made sharp so that it could pass more easily through the water or air. For they found, just as you have done with a bucket and the plank or the pupil stretched out and 'bunched-up', that the resistance of the air or water is greater for a wider surface.

Early attempts to overcome the drag of water were made by the Vikings in the construction of their long boats, and by French monks in the fifteenth century who carried out tests on hulls.

Imagine a rectangular block moving quickly through air or water as shown in figure 38. The front end will push water before it, and will therefore cause an area of high pressure. But the hind end will leave behind it a space that will be a region of low pressure or a partial vacuum.

If you make the front end pointed or rounded, the water or air will slide by more easily. But, if you leave the back square, there will still be a low-pressure space (or vacuum) as the object moves forward, and the effect of this will be to cause the object to be pulled backwards. This is known as *drag*.

You will now have the full explanation of why the bucket, or the bunched pupil, is harder to pull through the water than is a stretched out person. In making aircraft and cars, designers have been able to reduce the drag by tapering the back end of fast moving objects (figure 38). This then means the air pressure is reduced and there is very little 'dead' air to pull the object back.

The torpedo shape is called the *streamlined* form, which:

1. Is rounded at the front.
2. Reaches its maximum width near the front.
3. Has a steady taper to the rear.
4. Has a compact form with few or no projections.

Now look at the drawing of animals that live in water. To what extent are they streamlined?

Imagine that you are the designer of an aircraft, or a boat, or a car, and that you have worked out theoretically that the streamlined form would allow you to produce a faster moving object. You will now have to test your theory more thoroughly than by pulling buckets through ponds. One way in which this can be done is as follows:

1. Take several pieces of Plasticine, each weighing 1·0 g. Make one into a cube, one into a rectangular block, one into a ball, and several into torpedo shapes with varying tapers. You are now going to compare the speeds with which they sink in water.
2. Push a small piece of lead shot or a ball-bearing into that end of each model which you want to sink first.
3. Put each, in turn, into a 1 inch bore glass tube, filled with water, and time the rate at which each sinks over a marked distance.

Which shapes move fastest through the liquid?

If you find the objects move too quickly or wobble too much, you can slow down the movement by allowing them to sink in a very thin Polycell paste made by adding 10 g of Polycell (used as an adhesive for wallpaper) to a Winchester quart of water.

How many other animals can you list which have a streamlined form? (figure 37 and 39). State, in each case, where the animal lives – in the water, on land, or in the air.

Using Plasticine models and the long wide tube full of water you can devise experiments for yourself to show the effect of adding fins to objects of different shape and weight.

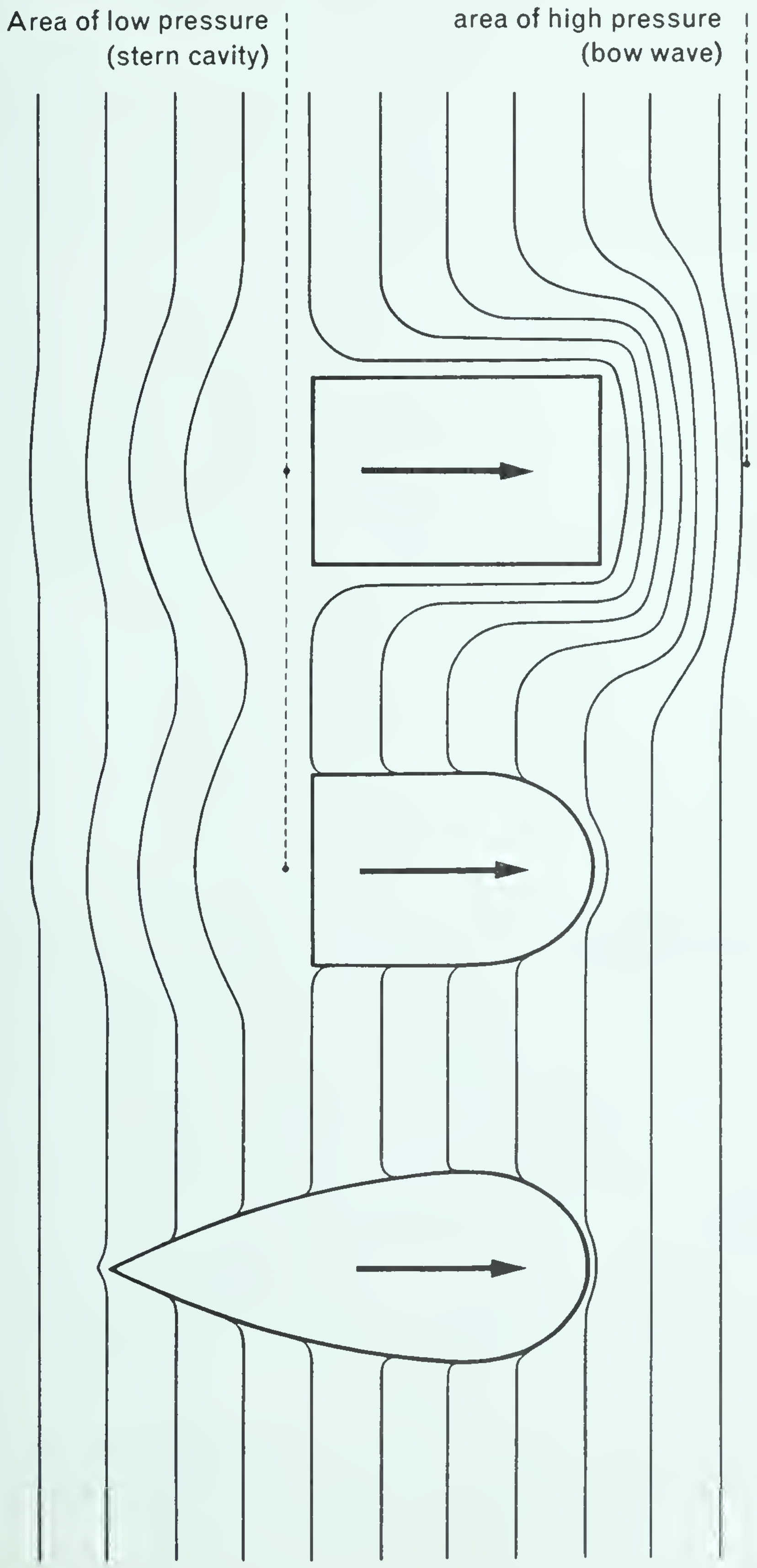


Figure 38
Diagram showing the pressures set up when bodies of different shapes move through water.

5.22 Shape and support

Apart from birds and insects which fly at high speeds, the streamlined form is commonest among water animals. As a result of your experiments or from your own experience of running through water, can you suggest a reason for this? Most land animals have different problems in moving about. As they are not supported by water they must be able to support their own weight as well as being able to move (figure 40).

Look again at the skeleton of the horse (figure 36). The parts which are most directly concerned with support and movement are the backbone and the legs. As well as having to support the animal the legs must be so placed as to give stability. A three-legged or tripod support is the most stable of all. This is nature's solution in animals which have to walk by raising one leg off the ground.

Just as we saw how some of the problems facing the designers of boats, aircraft, and cars were solved, and how the solutions could be used in helping us to understand the structure of some animals, so we can learn from the problems of bridge designers much that helps us to understand the structure of land animals. Some of the early bridges were made flat with supports directly underneath them and their designers were alarmed to find that they would tend to sag in the middle, and sometimes collapse altogether.

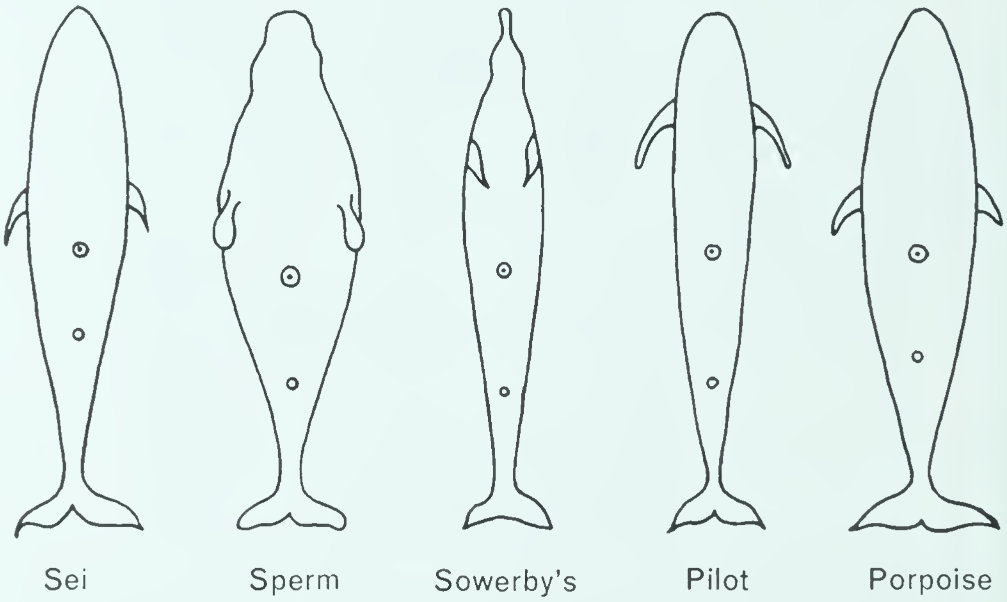


Figure 39
The shape of different members of the whale family.

Whether such problems of support were solved by observing animals, we do not know, but you can experiment with the various possibilities in much the same way as the early designers must have done. We will first look at the various possible angles of the four legs or supports and see which produces the greatest stability.

1. Take three pieces of Plasticine (about 20 g) and flatten them out into three rectangular blocks.

2. Now fix four full length milk straws to the corners underneath each block: one lot vertical, one splayed out sideways, and the last splayed out back and front.

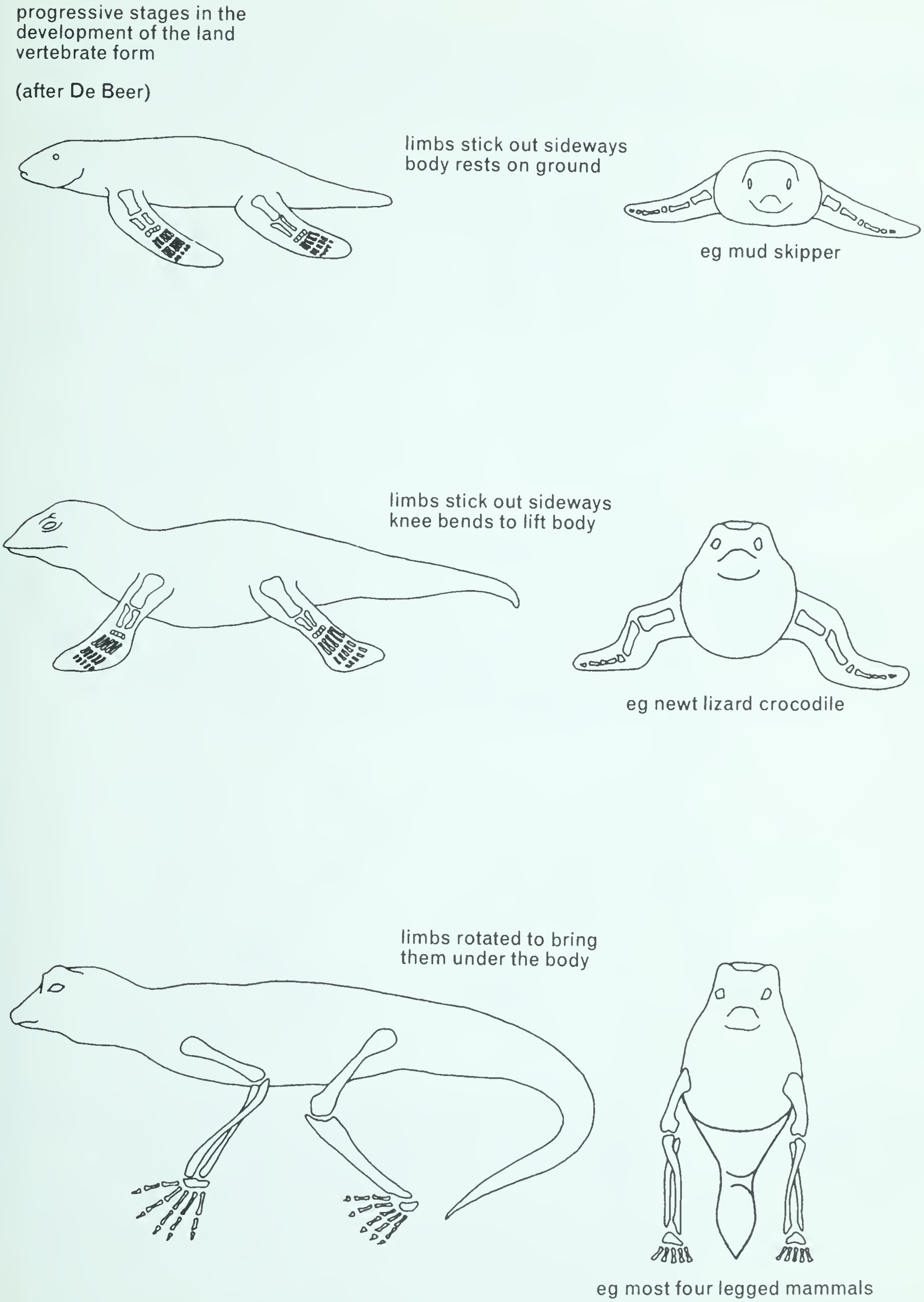
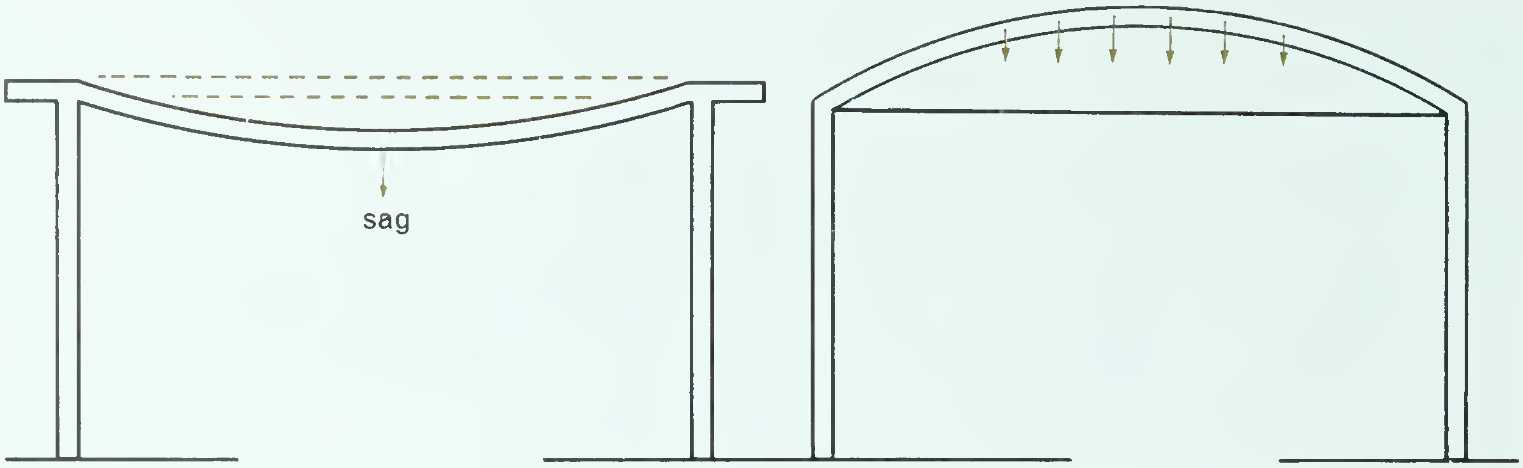


Figure 40
The problem of lifting the body clear of the ground in land animals.



a single flat support

the bowstring arch

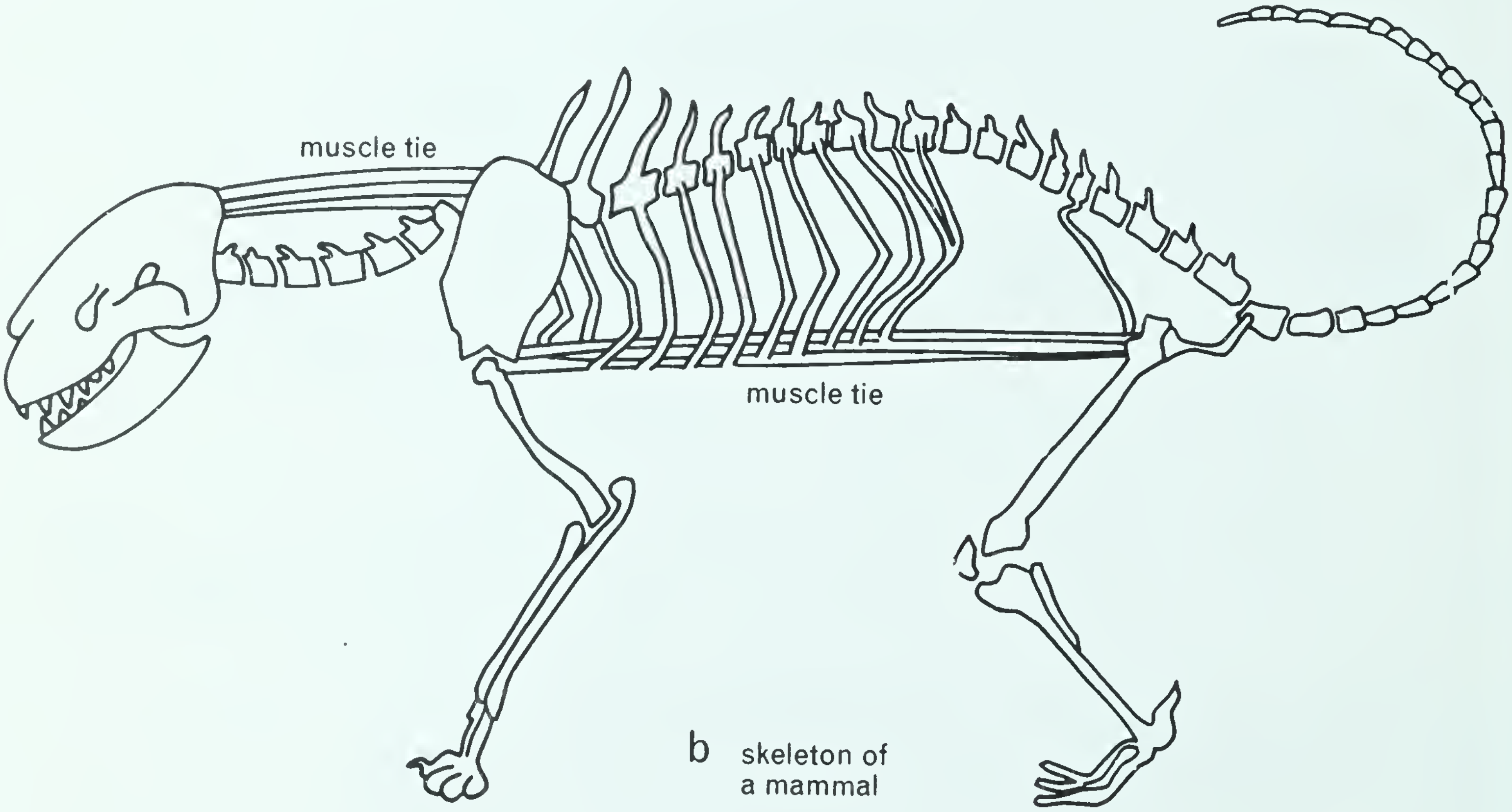


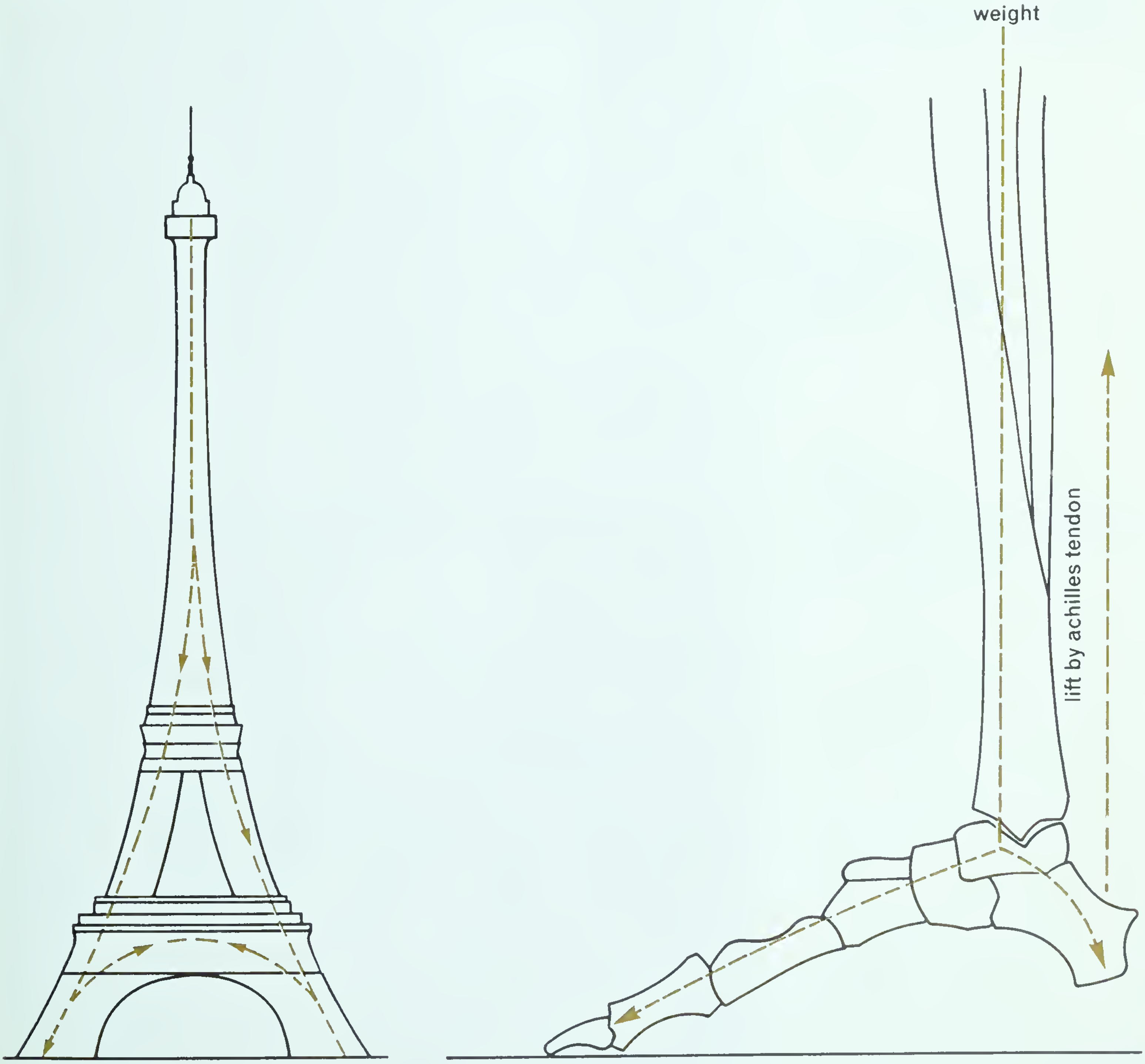
Figure 41
The principle of arching as illustrated (*a*) by a bridge, (*b*) by a mammal.

Which model is the most stable? Now look at the photograph of the giraffe viewed from the front (figure 44) and see if your solution of the problem of stability agrees with that of the giraffe.

Your own problems of remaining upright on two legs are much greater than those of the giraffe because, as you will have realized from the results of your experiments, you didn't have the advantage of having three or more legs splayed out. You rely on your posture and ability to balance to avoid toppling over. None the less, you will find that standing with your legs apart gives you greater stability, while using a walking stick or umbrella as a prop makes it even easier to remain upright.

When you splayed the straws out sideways you were distributing the weight, or downward force, of the Plasticine over a wider area. The same principle applies to an animal, bridge, or tower (figure 42). Another way of distributing weight, which can be seen from the skeleton of a horse or in the structure of many bridges, is to have the middle arched, with a tie between the two ends of the arch (figure 41). Do not imagine, however, that because a horse looks as though it has a flat or hollow back it will not bear your weight, or, because a bridge looks flat, it will collapse if you walk over it. It is only the centre of the weight bearing structure – the backbone or girder – which gains stability and strength from being arched.

Figure 42
a. The Eiffel Tower where the vertical load is distributed by the shape of the structure.
b. The human foot arch showing the weight transferred from the leg bones to ankle and foot.



a Eiffel Tower stability by spreading load

b the foot arch

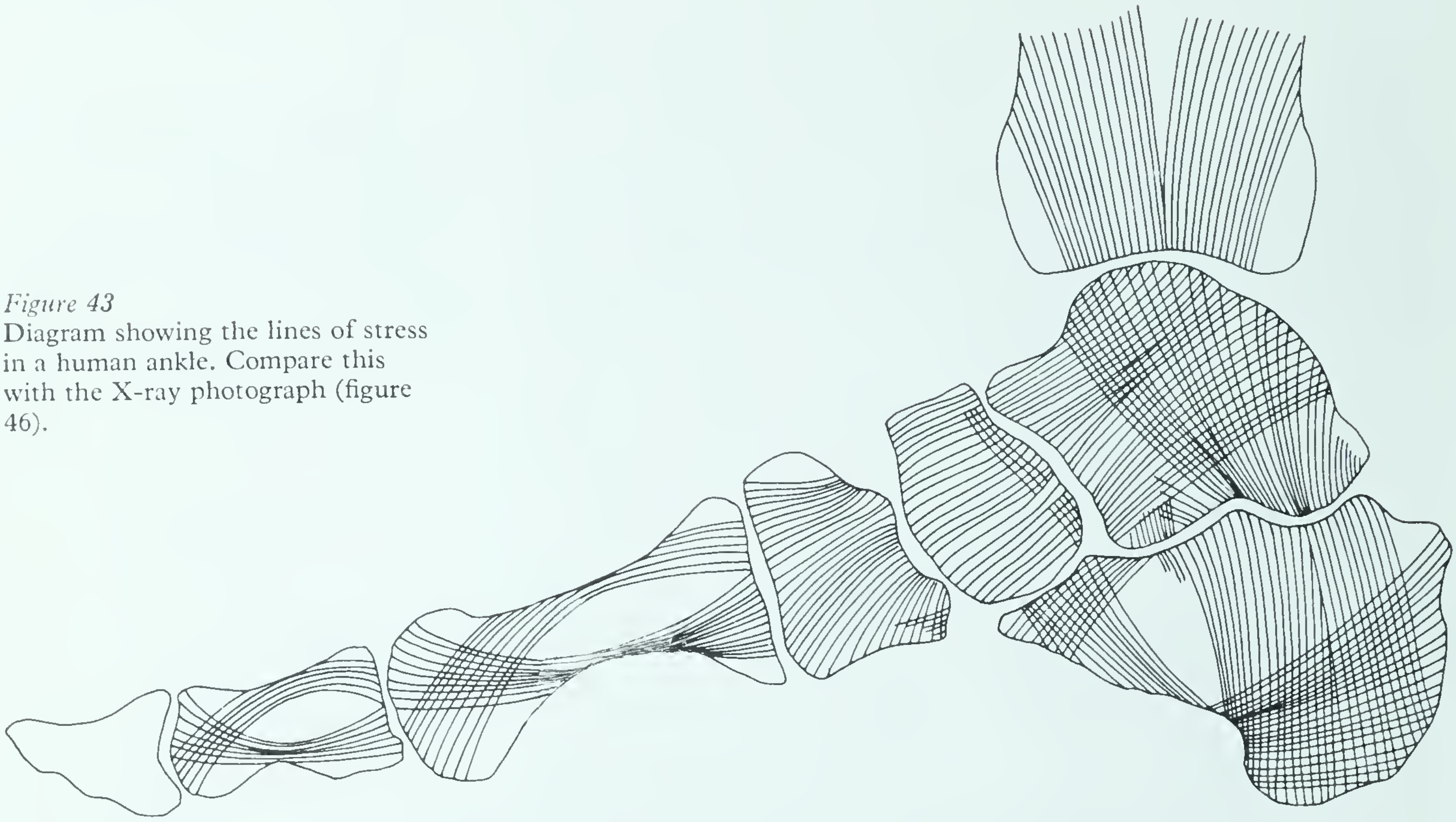


Figure 43
Diagram showing the lines of stress in a human ankle. Compare this with the X-ray photograph (figure 46).

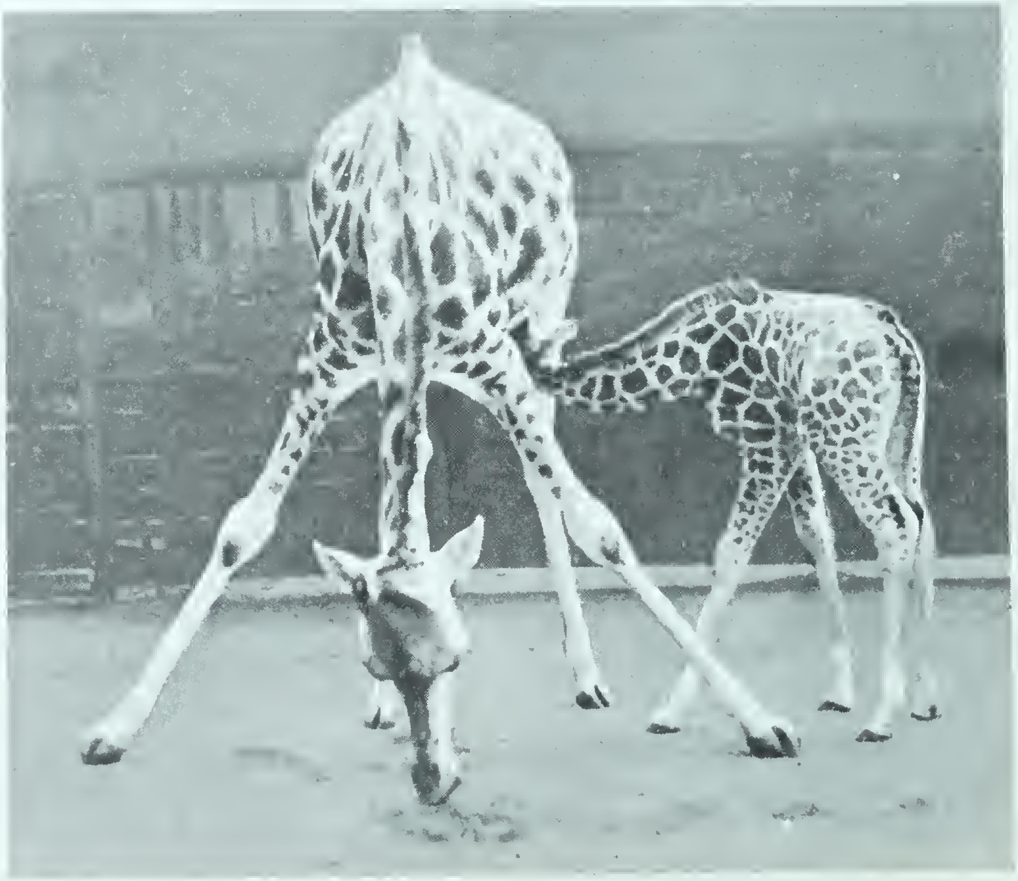


Figure 44
A photograph of a giraffe, showing the splayed legs. *By kind permission of the Royal Zoological Society.*

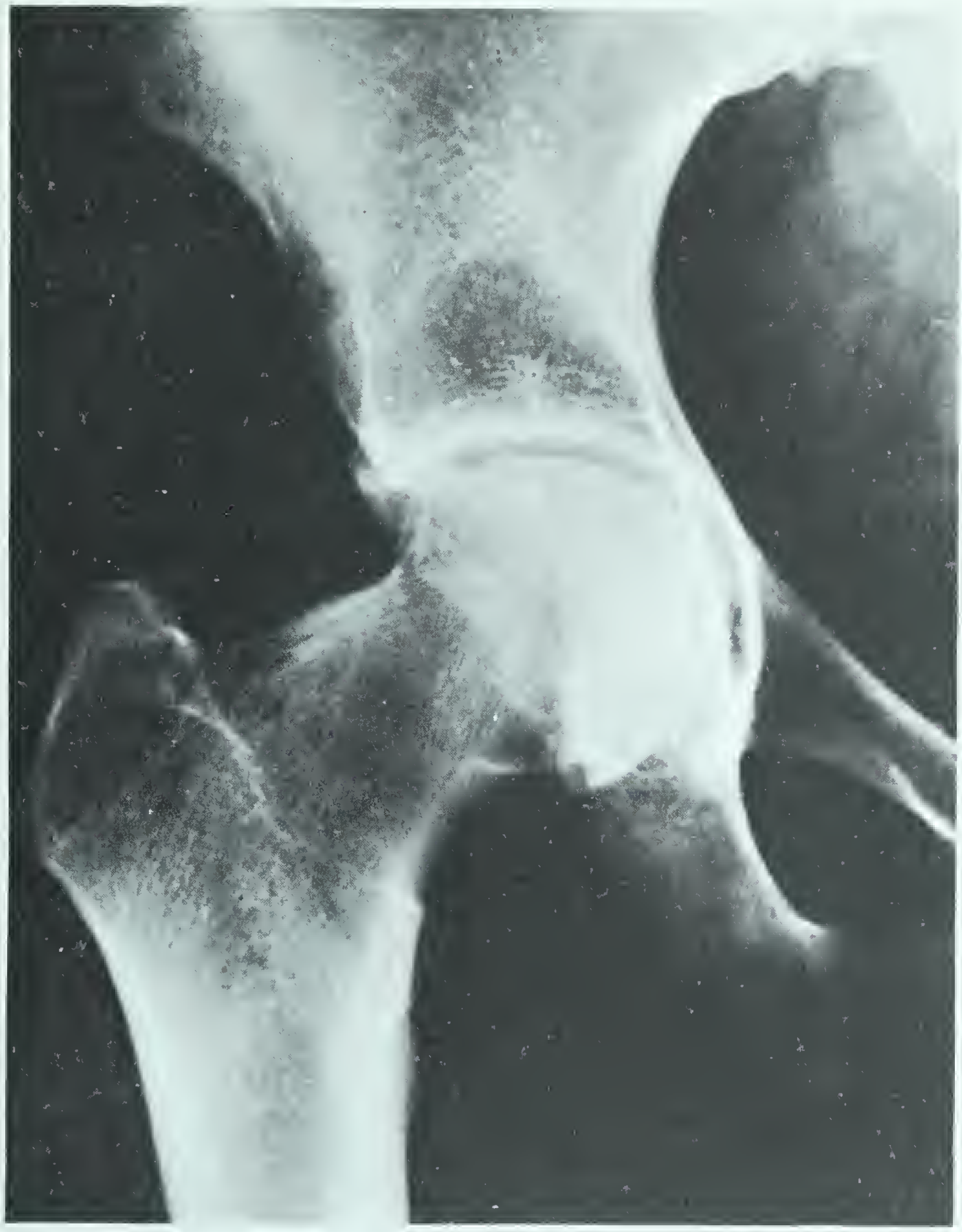


Figure 45
X-ray photograph of the head of the *femur. Copyright by Ilford Ltd, reproduced from* Positioning in Radiography, *7th edn.*

How do two-legged animals, such as birds and human beings, spread their weight onto a wider base and so gain stability?

Internal structures, particularly bone, also show this spreading of weight (figure 43). Look at the X-ray photograph of the ankle bones of the foot in figure 46. To see the arrangement of bone structure for yourself you will have to cut a large bone lengthwise with a saw. You can get a leg bone (*femur*) from the butcher and the result will be well worth the effort involved.

5.23 Shapes of plants and plant-like animals

We shall be examining the structure of plants in some detail in the next chapter. For the moment, perhaps you can work out for yourself why most animals should be so different in shape from the majority of plants? Also what similarities of shape and structure do land plants have to land animals? And what similarities are there between water plants and water animals? You will probably be able to answer these questions more easily if you examine those which are fixed as if they were plants. For instance, examine the skeletons of corals and 'sea ferns', and also the general structure of sea anemones. If you cannot obtain the real things, have a look at some pictures in a natural history book.

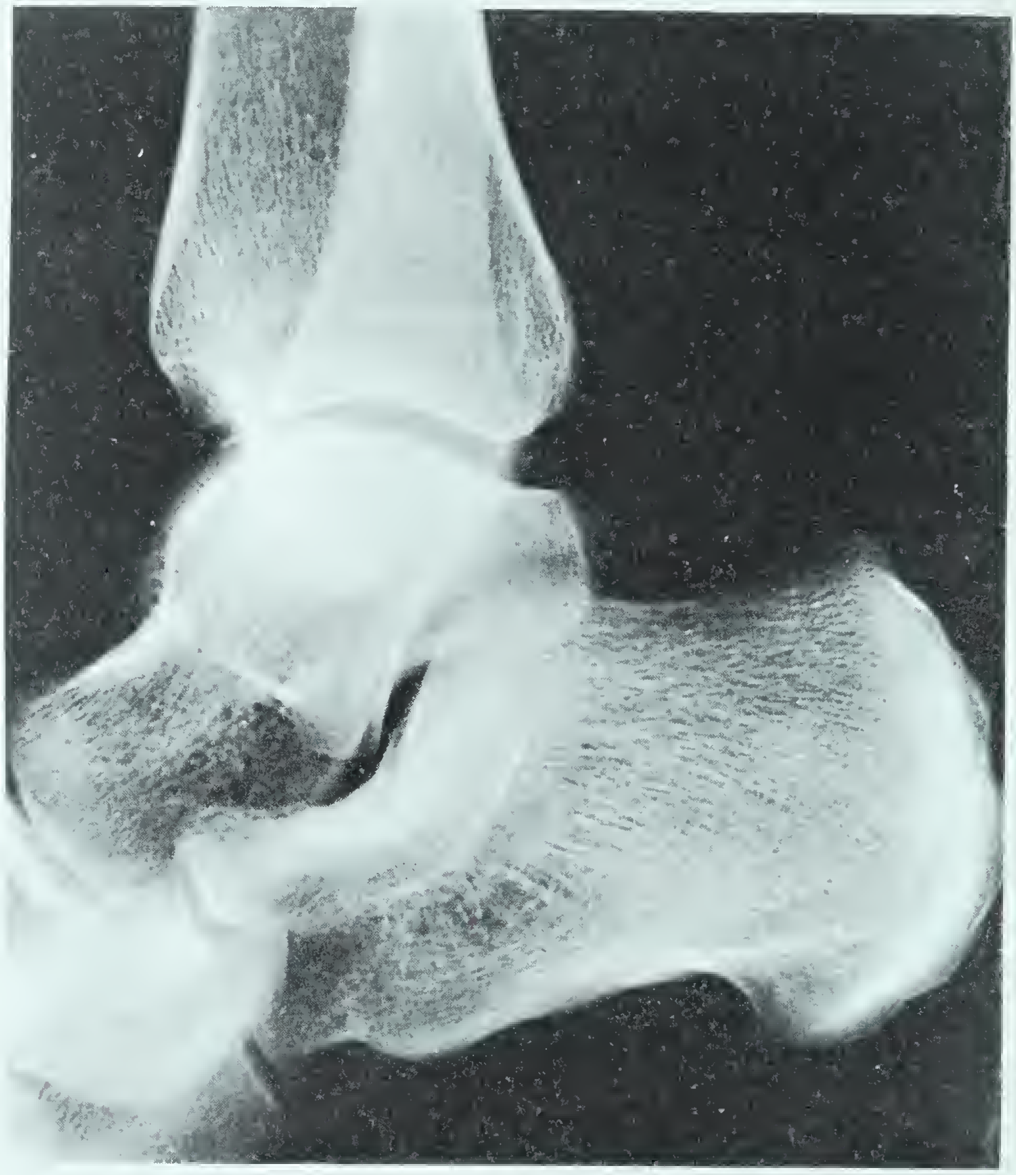


Figure 46
X-ray photograph of an ankle joint. (See figure 43.) *Copyright by Ilford Ltd, reproduced from* Positioning in Radiography, *7th edn.*

Summary

There is a wide range of sizes and shapes in living things. The necessity of an animal or plant to support its own weight limits its size. This problem is not serious for water organisms, for the upthrust of the water provides support.

The shape of an organism is related to its way of life and, similarly, the shape of an organ is related to the function it has to perform.

Background reading

Animals that burrow

For survival an animal must have three things – somewhere to feed, somewhere to shelter, and somewhere to breed. We have seen that the size and shape of an animal, as well as its ability to move about, largely decide the sort of places where it can live. We say that living organisms are *adapted* to survive in certain conditions but not in others.

Some animals have solved the problem of survival by making burrows where they spend the whole or part of their lives, depending on the extent to which the burrow provides food, shelter, and breeding conditions. Although they are of many different kinds, burrowing animals all have one thing in common – their shape. You can readily find by experience in the garden that the easiest object to push through the soil is a rounded rod (like the handle of a rake) with a sharp point in front. The best shape for moving soil is a large flat surface, like a spade. The shape of burrowing animals is, in fact, usually cylindrical and tapering. Let us examine the behaviour of a few burrowers and see how they are adapted to their strange existence underground.

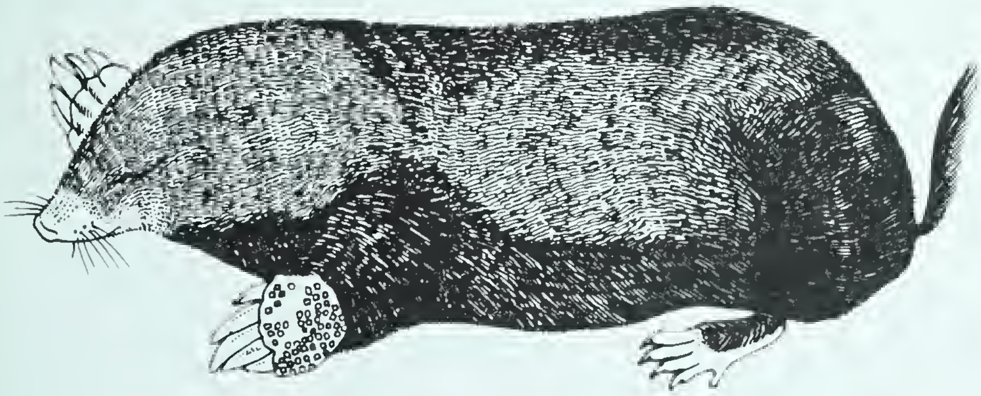


Figure 47
The mole, the best known burrower among our native mammals.
After The Handbook of British Mammals *published by Blackwell.*

Among our native mammals the best known burrower is the mole (figure 47) which spends almost the whole of its life underground. Notice how well the shape of the body agrees with our idea of a pointed rod. The mole is shaped much more like a cylinder than most mammals and its legs are short and stumpy. Notice too, how well the front limbs resemble a pair of spades. The thick-set shoulders show that the animal possesses powerful muscles which can be used in digging. Moles burrow at an astonishing speed. If you ever happen to capture one, let it go on fairly soft ground and see what happens. It will have disappeared within 10 seconds. It is often said that in the breeding season at least, male moles tend to move in straight lines as they travel underground ('He knows where he's going!') but females throw up molehills at random all over the place. This would be an interesting hypothesis to investigate further but designing a suitable experiment might present certain difficulties!

How do the male and female moles find one another underground to pair in the breeding season? Very little is known about how this happens beyond the fact that both sexes have well developed glands which produce different scents. No doubt smell must be the principal sense that brings the two sexes together.

Moles feed mainly on earthworms and the larger soil insects. There is, therefore, little need for them ever to come above ground since their burrows provide their three essential needs, food, shelter, and a breeding place. One of the problems facing a burrower is getting rid of the tunnelled earth. The mole does this by heaving the soil backwards with its powerful forelimbs, the result being the familiar molehills.

For most of us, the commonest burrowers of all are worms – either those which make unsightly worm casts on our lawns (the long worm – *Allolobophora longa*) or those we find living in such numbers on muddy shores near the sea and are used as bait by fishermen (the lugworm – *Arenicola marina*). If you examine the shape of an earthworm you will see how closely it resembles a pointed rod. Since the animal has no limbs for burrowing like a mole, it has to solve the problem of movement by eating its way forward through the earth. Worms feed largely on the humus contained in the soil, so while they are burrowing, they are feeding at the same time. All earthworms move about in this way making casts as they go, but only the long worm pushes the soil above the

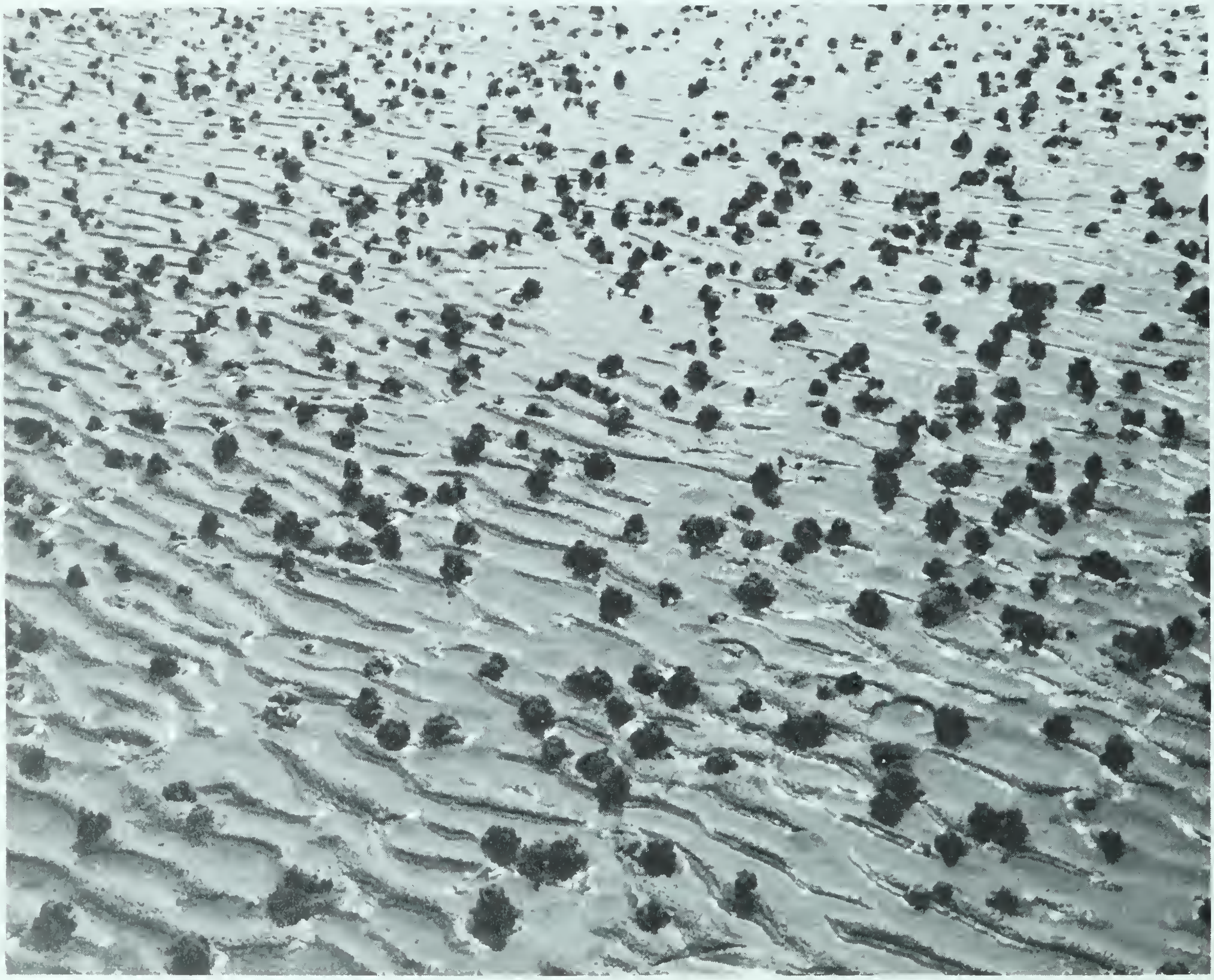


Figure 48
Worm casts at Black Rock Sands near Portmadoc, Caernarvon.
Photo: C. D. Bingham.

surface. The burrows made by worms provide them with food and shelter.

As earthworms rely on their burrows so much for protection both from drying up and from birds which eat them, the problem of mating presents certain difficulties. How are the worms to find one another? The difficulty is overcome in two ways. Unlike the mole, pairing occurs above ground where the chances of two worms meeting are greater; it also takes place at night when the animals are less likely to dry up or be seen by their predators. The creatures are hermaphrodite – each animal possesses both male and female reproductive organs. This means that when two worms pair each fertilizes the eggs of the other. In other words, two hermaphrodite animals can take the place of four with separate sexes. This is clearly an advantage for creatures spending most of their time underground. In most marine worms such as the lugworm there are separate males and females. Eggs and sperms are shed into the water where fertilization takes place. The chance of a sperm finding an egg will depend upon the numbers of both that are present. This, in turn, will depend upon the number of animals that are there to produce them. Sand and mud provide an abundance of food for burrowing worms, so it is not surprising that successful colonies tend to be very large, as figure 48 shows. Counts made on the mud flats of Holy Island (Anglesey) showed that at one time there were about 82,000 lugworms per acre – approximately seventeen worms every square yard.

A great many other animals, including many insects, have developed a burrowing mode of life. One of the best known is the death watch beetle which burrows into the timbers of old churches. Both the beetle and its larva are cylindrical in shape. The problem of removing its spoil is overcome by the insect eating its way forwards like an earthworm. All that is left are the undigested remains, or frass as it is called. The accumulation of frass under beams or furniture is usually the first sign of an attack by wood-boring beetles.

There is no end to the kinds of materials that animals select for burrowing. A group of molluscs (bivalves) even live in hard limestone rocks and succeed in making holes by means of chemicals. Acid is produced from the hind end of the body and this successfully dissolves the calcium carbonate of the rock.

Even birds use burrows for nesting and these species too are a compact and cylindrical shape, for example, the kingfisher and sand martin. Some, such as the puffin, are unable to dig themselves burrows but use holes or take over those ready made by other animals such as rabbits. Thus one species depends for its breeding place upon the burrowing activities of another.

Chapter 6

Size and surface in living things

6.1 Surfaces and their measurement

In Chapter 5 we saw how much plants and animals vary in size and shape. We now look more closely at the sizes to see whether such a study throws any light on the way in which the bodies of living organisms work.

The surface of an animal or plant is where it comes into contact with its surroundings – where it gets hot, cools down, gets wet, or loses water. Surfaces vary both in size and structure. Mammals have fur or hair, birds have feathers, frogs and toads have wet skins, and reptiles waterproof dry skins.

The first thing to do is to decide on ways of measuring surfaces and then to be clear what the measurements are for. As with all measurements, you should take care to state what units have been used. The metric system is usually used in scientific work, though we still measure lengths in feet and inches. Areas are measured in square centimetres (cm^2), volumes in cubic centimetres (cm^3), and weights in grams (g).

The most common measurements are:

1. Length – e.g. of animals (including or excluding the tail)
2. Area – e.g. of the surface of a leaf or of a whole animal or of the ground where plants are growing
3. Height – e.g. of plants or standing animals
4. Girth – e.g. of solid objects such as trees or the legs of large animals
5. Volume – e.g. of water animals. This can conveniently be measured by adding the animal to a known amount of water in a suitable container and seeing how much water it displaces
6. Wing span – e.g. of birds or insects
7. Weight. This is best measured directly. It can also be calculated approximately if we know an organism's dimensions and density (the weight of a unit volume of its body).

In this chapter we shall be largely concerned with measurements of surface area, and with assessing the advantages and difficulties which animals and plants experience because of the size and nature of their surfaces.

6.11 Weight, volume, and surface area

You will be familiar with measurements of length and height, but others are usually more useful in biology. As you will see by the end of this section, the relationships between the weight (bulk) of an organism and its surface area, and between its volume and surface area, are particularly informative. When we made cubes of Plasticine (section 5.11), we saw how an increase in bulk influences cross-sectional area. Let us now see how the surface area of an animal is affected as bulk increases.

It is difficult to experiment with actual animals, so we shall start by using cardboard boxes of different sizes instead. We shall measure their surface area and make comparisons with the volumes.

1. Select a number of cardboard boxes: the largest may be a shoe box, the smallest a match box.

2. Calculate the volume of each box by measuring the length, breadth, and height and then multiplying their three measurements together.

3. Measure the surface area by working out the areas of the six faces of the box and adding them together.

Do you find that the volume increases at the same rate as the surface area? If not, does it increase faster or slower?

4. Record your results as in table 1.

Volume								
Surface area								
Volume Surface Area								

Table 1. How to record the dimensions of boxes used to compare volume and surface

6.12 Measuring surface area

We shall now measure the surface area of various living organisms and see how organisms of the same weight, and those of the same volume, can differ in area. Or to put the same questions the other way round, how do organisms of the same surface area differ in weight and volume?

1. Take a mouse and weigh it.

2. Make a roll of paper the same length and diameter as the body of the mouse. When you unroll this it will give you, roughly, the surface area of the mouse.

3. Take a spray of leaves, say ivy, and prune it until its weight is equal to that of the mouse.

4. Measure the area of the leaves, ignoring the stems just as you ignored the legs and tail of the mouse. Leaves have two surfaces so you must include both in your results. You will now have two figures for each organism: the weight and surface area. By dividing the area of each by its weight, you can find the number of cm^3 of surface for every gram of weight. This is the (area/weight) ratio. Which has the larger surface compared with its weight, or (surface/weight) ratio, the compact body or the spreading one?

5. Now make rolls of paper the same size as your own body, head, both legs and both arms. Unroll them, measure the area of each, and then add them all together.

6. This will give you a rough idea of the surface area of your body. Divide this figure by your weight, which you should work out in grams. This will give you the (area/weight) ratio for your body. How does this figure compare with the one for the mouse?

7. Record your results as in table 2.

Name of animal or plant	Weight	Surface area	Area / Weight

Table 2. Recording measurements of the area and weight of various living things

6.2 Surface area and temperature

The surfaces of living organisms control, among other things, the amounts of heat gained from or lost to their surroundings. We shall first consider how the extent of the surface affects the body temperature of a living organism.

Plants take in light and heat from the sun and this energy enables them to manufacture their own food. Animals may also use heat from the sun for warmth, but many of them generate sufficient heat within their bodies to raise and maintain their temperature above that of their surroundings. Such creatures are said to be *warm-blooded*.

It is different with some insects, such as butterflies, which are unable to fly when the sun goes in. Most insects cannot fly in cold weather. Lizards become sluggish on a cold day out of the sun, since the proper working of their muscles depends largely upon warmth.

Human beings and other warm-blooded animals have a more or less constant temperature. Even so, there are small variations, as you can see for yourself by taking your temperature at intervals throughout the day. In order to remain warm-blooded animals must somehow prevent loss of heat when the surrounding temperature is low and increase loss of heat when they are very active or their surroundings are hot. This important regulation of heat loss depends largely on the nature and size of the body surface.

Other animals whose body temperature varies continually with that of their surroundings are said to be *cold-blooded*. Insects become inactive in cold weather because they rely for the proper working of their muscles on heat they absorb from the outside. Many cold-blooded animals such as fish live in water but, as we saw in the last chapter, water animals need less muscle power to move about than land animals owing to the buoyancy of the water.

If we assume that cold-blooded animals are entirely dependent on the heat they absorb through their surfaces from the sun, what would you expect the sizes of such creatures in temperate countries to differ from their sizes

a. In the tropics?
b. In arctic regions?
c. In the sea?

What is the largest cold-blooded animal you have heard of in each of these regions?

6.21 Heat loss and surface area

You can now try an experiment to study this question more precisely, and to see whether surface area affects heat loss. You have seen earlier in this chapter (section 6.12) that the ratio you get from dividing the surface area of a living thing by its weight becomes smaller as the animal gets larger. We now want to see if this principle can be related to the amount of heat lost from the bodies of animals of various sizes.

1. Fit up two round-bottomed flasks – one 100 cm^3 and the other 500 cm^3 – with thermometers (figure 49).
2. Fill the bulb of each flask with nearly boiling water.
3. Record the temperature in each flask at two minute intervals.
4. Plot a cooling curve for each flask with time on the horizontal axis and temperature on the vertical axis, as in table 4.
5. Now work out the (surface area weight) ratio for each. The approximate surface area of the 500 cm^3 flask is 330 cm^2 and that of the 100 cm^3 115 cm^2. The weight is the weight of the water. Which has the greater (area weight) ratio and which cools the more rapidly?

Time in minutes	Temperature of 500 cm^3 flask. C	Temperature of 100 cm^3 flask. C
0		
2		
4		
6		
8		
10		
12		
14		

Table 3. Recording temperatures in the two flasks

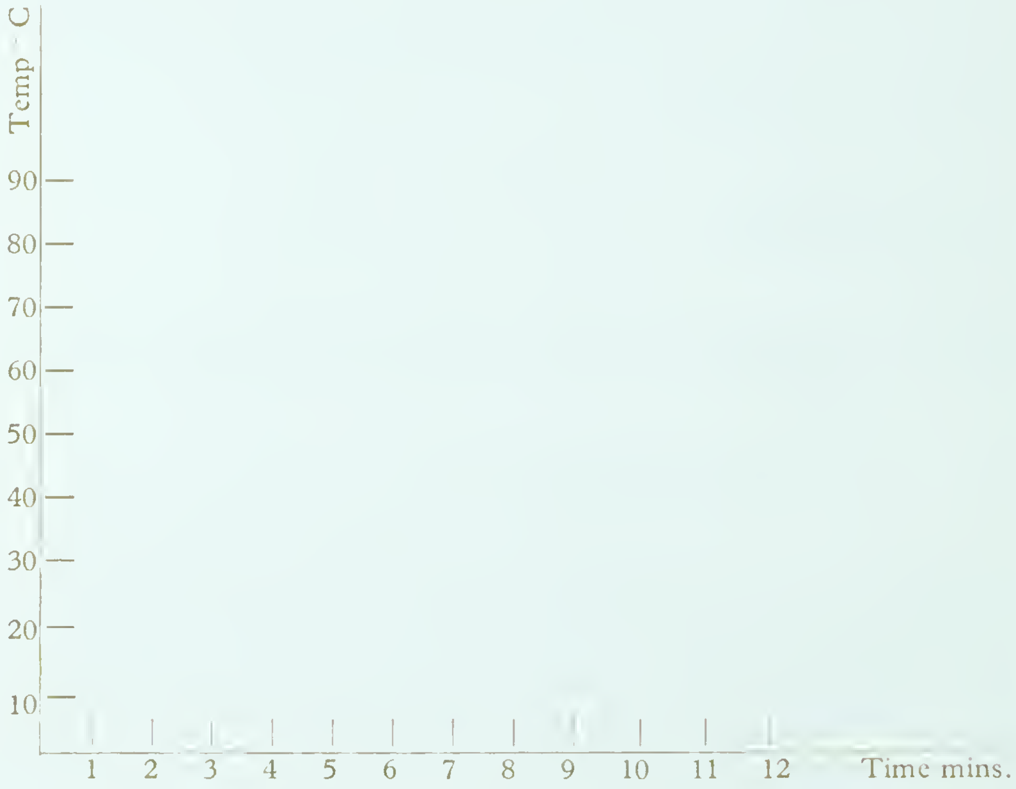


Table 4. How to arrange a graph for plotting the cooling curve for 500 cm^3 and 100 cm^3 flasks.

6.22 Keeping warm

Preventing loss of heat is more difficult for small warm-blooded animals, or during exposure to very cold conditions. Can you think of ways in which animals are guarded against this heat loss? The following investigation will help you to answer this.

1. Fit three round-bottomed 100 or 250 cm^3 flasks with thermometers.
2. Leave one flask uncovered, stick feathers all over the second, and cover the third with cottonwool.

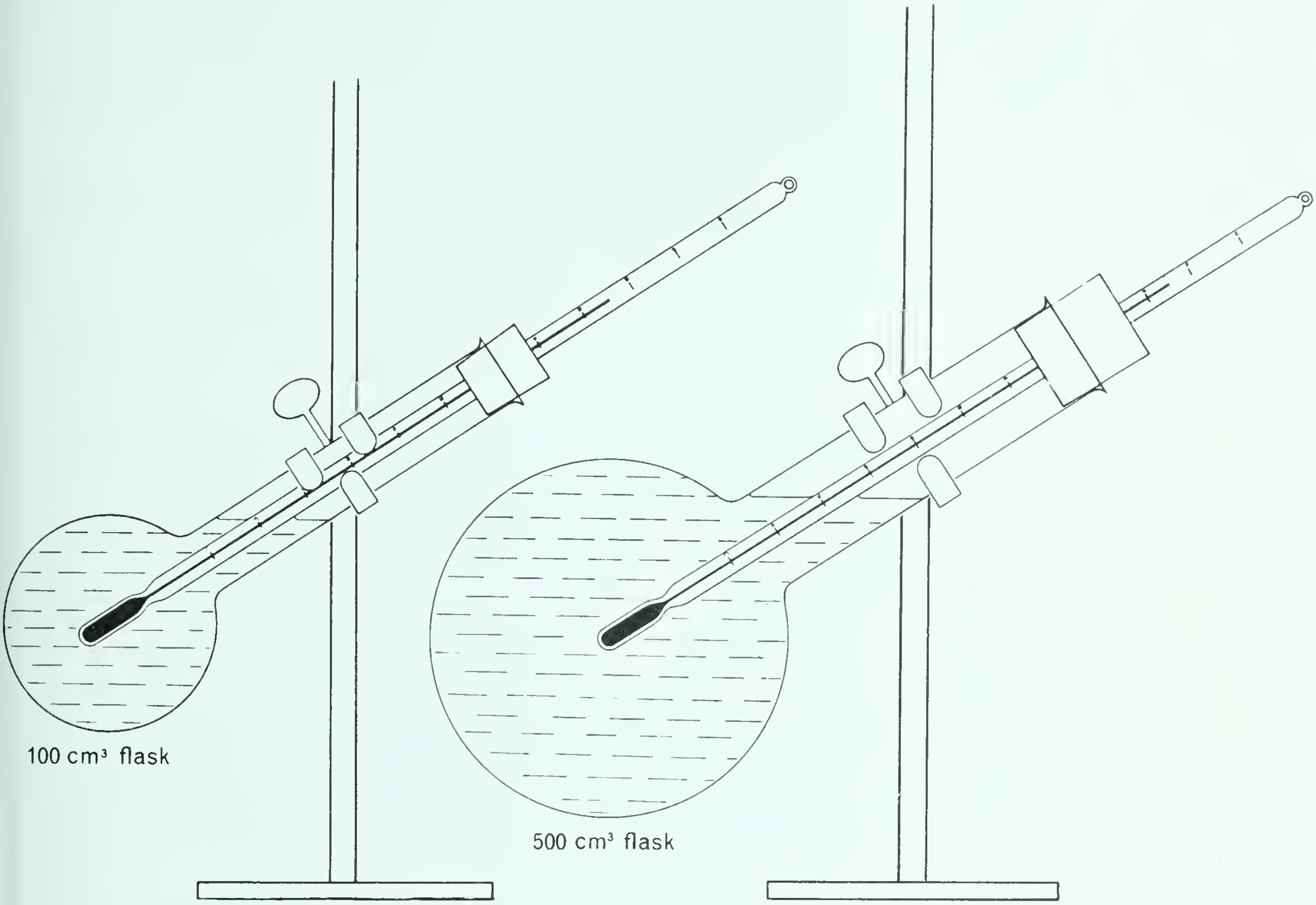


Figure 49
Method of supporting flasks to record cooling.

3. Each flask is filled with nearly boiling water and its temperature taken every two minutes as in section 6.21.
4. Cooling curves can then be drawn to show the speed at which the flasks cool.

Using the results from these two experiments, can you explain the following:

a. Warm-blooded animals living in arctic regions, both birds and mammals, are on the average larger than those living in warmer climates.
b. The smallest mammals and birds live in hot climates.
c. Shrews can just survive in the British Isles.
d. Humming birds are found only in the tropics. The weight of the smallest humming bird is less than 2 g.
e. Aquatic warm-blooded animals in northern or southern seas are very large (whales, seals, dolphins).
f. Polar bears have thick fur.
g. Babies should always be kept in a reasonably warm temperature. Many have died in bedrooms that were too cold, even when they have been covered. Adults, however, can stand extreme cold.

6.23 Keeping cool

Very large animals – for example elephants – which live in hot climates have so small a (surface/weight) ratio that they cannot lose heat quickly enough. Their surface is increased by their large floppy ears which lose heat rapidly.

Long legs, folds of skin, long tails, and other projections in various animals act as cooling devices in much the same way as fins on a radiator in a house. You can show how folding increases a surface by the following experiment.

1. Fold a piece of foolscap paper as you would to make a paper fan. However, instead of completing the fan, fasten the two edges together to make a fluted cylinder.
2. Make a plain cylinder of the same volume – it will have a diameter half way between the outside and the inside points of the folded cylinder.
3. Open out both flat again and see how much more paper there is in the fluted one than in the plain one.

As a further experiment:

1. Take a bunch of grapes and count their number.
2. Pick off a grape of average size, peel it, and measure the area of the skin by putting it flat on a piece of graph paper.
3. Multiply the area of this one piece of skin by the number of grapes in the bunch and you will have the total surface area of the bunch. Compare this with the surface area of a paper bag which will just take the bunch of grapes.
4. This will give you a good idea of the variation in the surface area of objects of similar volume but with different kinds of surfaces. The bag has a simple surface; the grapes have a complex folded one.

Land animals in very hot climates often cool themselves by bathing in rivers and lakes as do the hippopotamus and rhinoceros. Cooling is achieved in two different ways. First, more obviously, the water is itself cooler than the surface of the animal so that heat will be carried away from the surface. But heat will also be lost because water has a cooling effect when it evaporates from a surface. Sometimes this effect can be quite remarkable, as when we bathe in a very hot dry climate with a temperature of 80°F or more in the shade. On coming out of the water, the evaporating and cooling can be so rapid that we actually shiver with the cold!

All animals lose heat to some extent by the evaporation of water from parts of their bodies. Human beings sweat through the pores of the skin and other animals, which depend upon fur to prevent loss of heat, lose water through other surfaces. For example, the dog loses water from its tongue when it pants, and a cat loses water through its pads. Next time you go to a zoo in summer, look at seals, polar bears, gazelles, and monkeys and see if you can decide how they are attempting to keep cool.

In general, mammals living in hot climates have thin fur and a number of projecting surfaces such as big ears. Those that live in cold climates have fewer projections, dense fur, and often a thick layer of fat under the skin which acts as an insulator. (The blubber of a whale is one example.) They also tend to be larger and more compact than those species that live in hot conditions.

6.3 Retaining water

More than half the weight of all living things consists of water. In order to maintain his supply of water in a temperate climate man needs approximately six pints a day which he obtains partly from his food but mostly as liquid. Of this he loses about 2 per cent in sweating, through breathing, and as urine. By contrast, worms lose as much as 60 per cent of the water they take in daily. Insects, on the other hand, are highly efficient at retaining water and many of them lose less than 1 per cent of all they take in. How do different sizes and kinds of surfaces affect the ability of a living thing to retain water?

1. Soak a handkerchief in water and screw it up into a tight ball.
2. Soak another handkerchief in water and hang it up next to the one that is screwed up.

Which dries more quickly? Work out the ratio of the surface area of the one that is screwed up to the one that is hung out. Remember that, like the leaf, the handkerchief has two sides.

You can repeat this experiment more precisely using blotting paper.

1. Take four pieces of blotting paper of the same size (approximately 8 inches by 5 inches).
2. Leave one intact, cut the second into two equal pieces, the third into four equal pieces, and the fourth into eight equal pieces.
3. Arrange them in four piles, on a sheet of glass, as they are in figure 50.
4. Soak each pile of blotting paper with water, allow them to drain and then leave them out on the bench to dry.

There is an equal quantity of blotting paper in each pile; they are all equally wet; but do they dry at the same rate? What is the connection between the area of surface exposed and the rate at which the blotting paper dries? If you use pink blotting paper for this experiment you can see the progress of the drying by the change in colour from red to pink. Note the time taken for each pile to become dry.

Now devise an experiment with beakers of different sizes to see if the same volume of water evaporates at a different rate when the surface area is varied. Try also the effect of covering the surface of the water with a thin layer of oil.

Making a general comparison of the surface areas of plants and animals, it is clear that plants, with all their leaves, have a larger

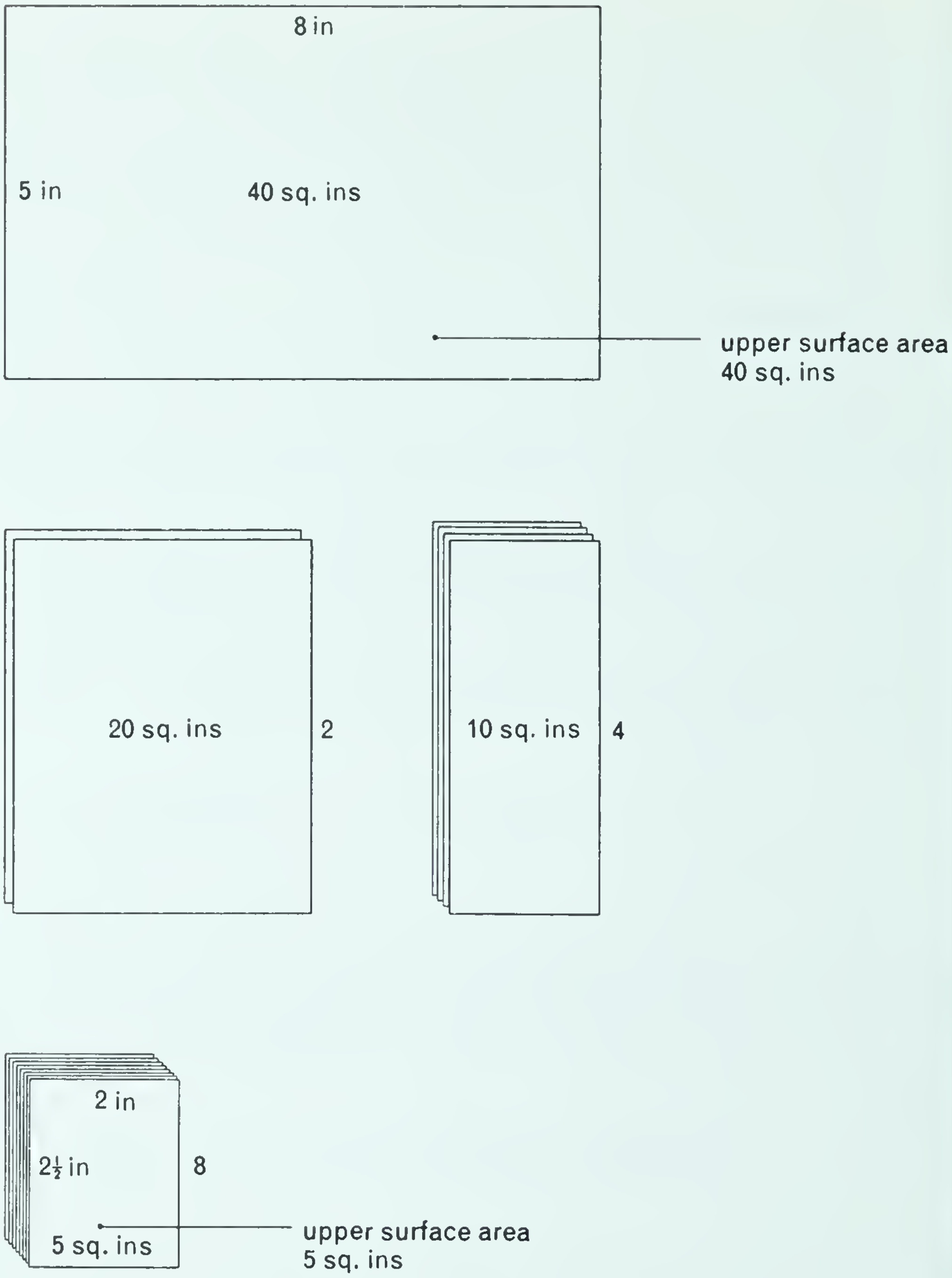


Figure 50
Investigation of evaporation from a surface. Blotting paper on a glass plate.

surface, relative to their bulk, than animals. Can you think of any evidence that would suggest that they lose a great deal of water as a result? Devise a simple experiment yourself to show that plant leaves do, in fact, lose water to the air. Leaves rely on water to remain rigid. Without water they become limp.

When a leaf loses water faster than it can be replaced, the plant wilts. But all leaves do not wilt with equal ease, although they may have the same surface area. Let us see what other factors affect the loss of water by leaves.

1. Find a geranium leaf, an ivy leaf, a holly leaf, and a cactus 'leaf', all of roughly the same area.
2. Leave them on the bench to dry. Which leaves become limp? What do you notice about the nature of the surfaces of those leaves that take the longest to wilt?
3. Try wetting the leaves first with water and then with a liquid such as paraffin which dissolves oil and wax. Does the reaction of

these two liquids with the surface of the leaves suggest to you what might be waterproofing the ones that wilt most slowly?

6.31 How is water conserved?

Although it is an advantage to animals to be able to lose heat by the evaporation of water through their skins, it could be dangerous if, in very hot climates, the water loss were not controlled in some way. If it were not the animals might soon lose too much water and die. We shall now see how animals are protected against the danger of drying up.

Using any animals that you can think of, make three lists under the following headings:

a. Animals whose skin is always wet.
b. Animals whose skin can be either wet or dry.
c. Animals which have a dry skin which is difficult to wet.

Which of these animals can be found in dry places and which are never found there?

One way in which animals maintain a supply of water is by drinking. But you can probably think of several animals that need to drink no water throughout their lives. Cows normally get most of the water they need from the grass which they eat, but if they are kept indoors and fed on hay and artificial foods, they must have drinking water too. Sheep are a borderline case. In most seasons in Great Britain they can live well without water, but during droughts they must drink water, otherwise they will die. During one great drought in the nineteenth century sheep were dying in great numbers for lack of water. Many flocks were saved by being grazed on the sea pea – a plant which grows on shingle beaches and has rather fleshy leaves containing good supplies of water. Dogs and mice must have liquid water to drink. An insect such as the locust requires no water if fed on fresh green plant material. But it does need water if its food consists entirely of dry matter such as hay.

As we have seen, in our temperate climate adult people need about six pints of water daily. A few animals, however, live in very dry conditions on almost dry food and yet manage to survive. The mealworm is a good example. If you examine one closely, you should be able to suggest why it is able to exist on so little water. You can imitate the sort of waterproofing that it possesses by enclosing your wet handkerchief or wet blotting paper in a Polythene bag. (What effect does this have on the rate at which these materials dry?) The shiny material that surrounds the buds on plants, the horny material (chitin) with an outer waxy layer which encases insects, and the wax on the surfaces of many animals and plants are all waterproofing materials and to a greater or lesser extent prevent the loss of water.

In the experiment you devised to show the rate of evaporation from the same volume of water with different surface areas (section 6.3), was there any loss of water when the surface was covered with oil?

6.32 The advantages of keeping dry

When you get out of a bath your skin is covered with a film of water about one-fiftieth of an inch thick which weighs about 1 lb – an additional weight that you yourself may not be able to detect. However, if a small animal gets wet, the film of water is still the same thickness and, because the (surface area/weight) ratio is so much larger, the weight of water may easily be greater than that of the animal itself.

Thus if a fly falls into a bucket of water it will remain there until it drowns, weighted down by the water on its body and wings. Similarly, if a mouse gets thoroughly wet the weight of water that it carries is roughly equal to its own weight (about 1 oz or 25 g) and it can only just move about.

Not only does this film of water prevent the animal from moving, but it also affects other functions. For instance, wet fur is much less effective in preventing loss of heat. You will probably have noticed that animals fluff out their coats to keep themselves warm; this is not possible when they are wet. Animals also lose additional heat when the water on their fur evaporates.

You can test the effectiveness of various surfaces in repelling water by the following experiments:

1. Dip a small piece of blotting paper into melted paraffin wax and allow it to drain and cool.
2. Compare the action of water on this paper and on ordinary, unwaxed blotting paper.

Next cover a series of test-tubes of the same size with different kinds of paper – writing paper, blotting paper, and waxed paper – and also with felt.

1. Record the weight of each tube with its covering and one tube uncovered.
2. Dip the tubes in water and allow the surface of each to absorb as much water as it will.
3. Weigh each tube again and record its increase in weight.

Which materials take up the most and which the least amount of water? Does oiling or waxing the paper affect the amount of water absorbed?

Flies, mice, and other small animals with large surface areas are fortunately not often exposed to extremes of wetness which might prove fatal. All of them have some protection against the ill effects of excess water usually in the form of a covering of wax or oil which repels water. Many large animals too, particularly birds, produce some kind of oily, water-repellent substances, but their importance varies with different species, depending on the kind of life they lead.

When a bird preens itself, it distributes oil from special glands to all its feathers. To birds that live in water, such as ducks or swans, it is essential that their feathers should be kept dry, for air trapped in and between the feathers keeps birds warm and, more important, makes them buoyant.

You can see how the oil in the feathers of birds repels water if you carry out the following experiment:

1. Take a feather from a water bird, dip it in water, and shake it. What happens to the water?
2. Now add a few drops of detergent to the water before you dip the feather in. (This reduces surface tension and makes it easier for water to spread out and wet a surface.)

What happens to the water when you shake the feathers now? What would happen to a duck if the pool on which it swam contained detergent? You must not test this hypothesis as it would be cruel to the duck and would contaminate the pond.

6.33 The advantages of keeping wet

In your list in section 6.1 of animals with wet skins, you probably included frogs, toads, earthworms, and similar animals. These have the reverse problem of needing to be wet in order to survive. The reason for this is that they breathe through their skins and the oxygen from the air is absorbed when it dissolves in the moisture on their body surface. Such creatures survive in places where they will not be in danger of drying up: in the soil, underneath vegetation, under stones, or near water. Sometimes a covering of slime helps them to keep wet. The slug is a good example of this. Other animals, like the snail, have an additional protective covering. If you look at a snail in hot weather you will see how it uses the slime it produces to protect itself even more completely against drought.

The woodlouse needs some protection against drying out and therefore normally lives in dark crevices, inside moss 'cushions', under bark, or under stones. It can also make journeys in the open air without drying up, but it does so chiefly in the cool of night. The earthworm needs protection from drying up at all times and is more like an aquatic animal which happens to live in soil. It is even able to survive when submerged in a tank of water, as you can see by observing what happens to worms placed in aquaria as food for fish.

Summary

The increase in the ratio of surface area to weight as living things get smaller is an important factor which affects their ability to survive. This ratio also increases in organisms which are less compact, particularly plants.

Warm-blooded animals depend on the size and nature of their body surfaces to maintain a constant temperature. The smaller the animal, the greater the amount of cooling that takes place at its surface.

Cold-blooded land animals are also dependent upon the size and nature of their surfaces, which they use to gain heat from their surroundings.

Water loss through the surface is most rapid in small animals and in plants which have a large (surface area/weight) ratio. Many living things are protected against too rapid a loss of water by some sort of waterproofing.

It is essential for some animals to keep dry. Many of them are covered with a water-repellent substance such as oil or wax. Other species must have a wet skin at all times in order to breathe and these, like the slug, always live in damp or sheltered places, sometimes secreting slime which prevents their drying up in hot weather.

Background reading

Organisms that float

If you go out in a boat on the sea, and trail a net made of fine mesh silk on a line so that it is only a few feet below the surface, the chances are that when you reel it in you will find that it is coated with a fine green slime. If you examine some of this slime under a microscope you will discover that it consists of numerous minute green plants looking something like those in figure 51. These tiny floating organisms are called *plant plankton* (from the Greek word meaning 'wandering'). They are very important in the economy of the sea since they provide the food for vast numbers of small animals (*animal plankton* – figure 52). These, in turn, are the food of larger animals many of which, especially the fishes, are eaten by man.

If you let some plant plankton float in a drop of water under a microscope you will see that nearly all the minute plants lack means of moving about. Since all green plants need light in order to live, it is clearly important for the plankton that they should remain in the zones of the water near the surface where there is plenty of light. But if the organisms cannot swim, why do they not sink to the bottom? After all, they are slightly heavier than water.

You may have learnt in your physics that at any point on the Earth, all things are attracted by gravity towards the centre. In other words, you would expect all things to fall towards the earth at the same continually increasing speed. You might think of putting this idea to the test by the familiar experiment of placing a small piece of paper (roughly 1 cm square) on top of a penny. Now drop the penny with the paper on top from a height of about four feet. What happens – do the coin and paper fall at the same speed? Now try the same experiment holding the coin in one hand and the piece of paper in the other. Let them drop together from

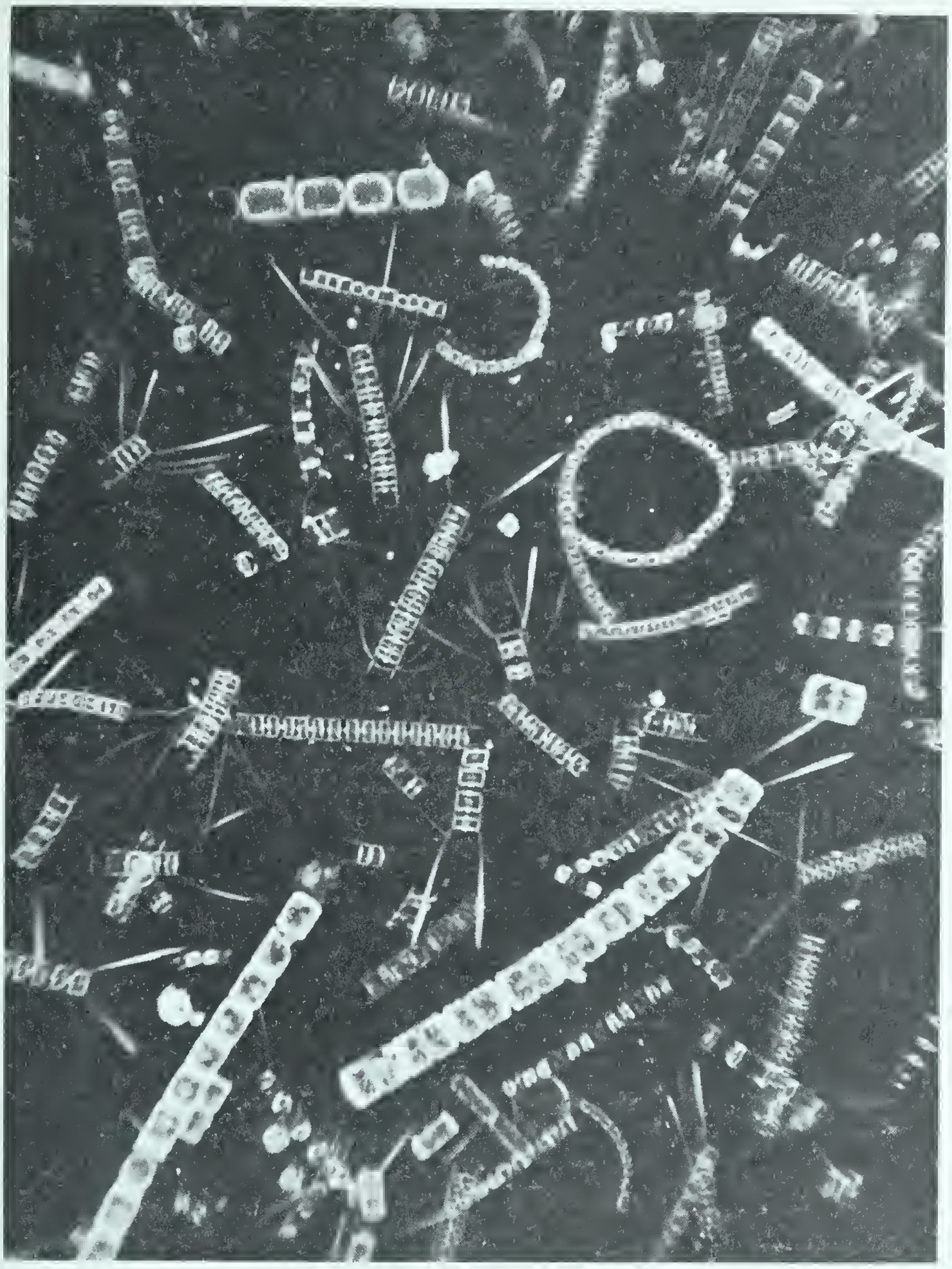


Figure 51
Living diatoms of the marine plant plankton (× 50). *Photo by Dr D. P. Wilson.*

four feet. Which reaches the ground first? If you took two pennies or two pieces of paper of the same size and compared their rate of fall what would you expect to happen?

Assuming that the penny and the paper are both equally attracted towards the centre of the Earth, their different rates of falling when alone might be due to the way in which the matter they are made of is distributed. Is it densely packed and together, or spread through a comparatively large volume? Is it concentrated into a compact shape with a smooth regular surface, or is it spread out in such a way that the surface is very large indeed.

Now try another experiment. Use an English penny and a disc of aluminium of exactly the same size and shape. Their weights are different (the aluminium disc is lighter). Fill a container of water (a kitchen saucepan will do well) and let them drop together starting off just below the surface. Which gets to the bottom first? If you cannot get or make an aluminium disc try any two objects

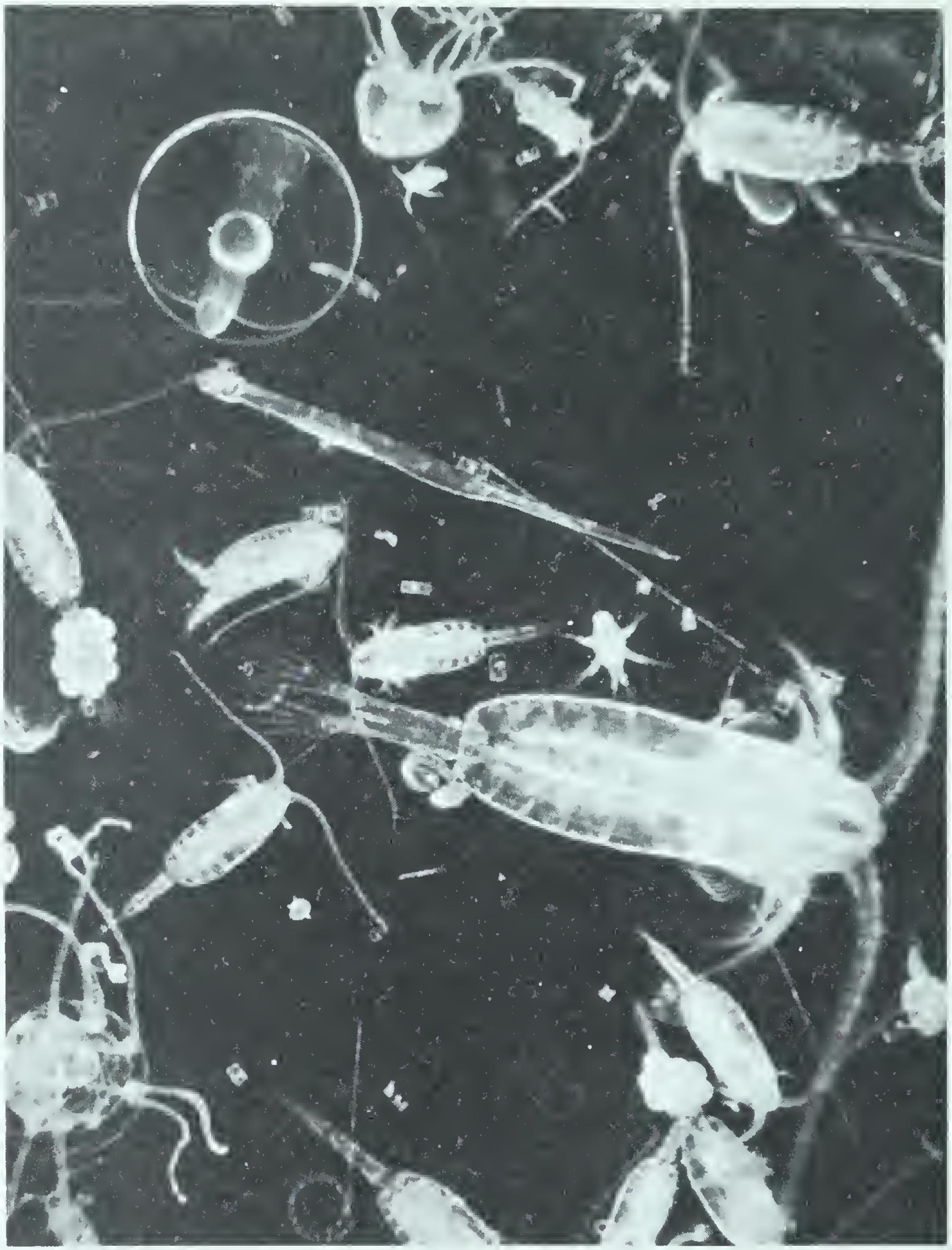


Figure 52
Living marine plankton, showing crustaceans and *Medusae* (× 25).
Photo by Dr D. P. Wilson.

which are the same size but different weights, e.g. a lump of sugar and a cube of Plasticine.

As a last experiment take two pieces of tin foil which are exactly the same size (about six inches square) and therefore the same weight. Roll one piece up into a tight ball but fold the other over twice and then cut the edges with a pair of scissors to make them jagged. Which piece has the greater surface area? Now let the two pieces fall through the water as in the previous experiment. Which reaches the bottom first?

These simple experiments help to show why it is that plants in the plankton fall very slowly through water in which they are living even though they may be more dense than their surroundings. For the plankton has almost the same density as the water, which means that the downward pull of the Earth is almost, if not quite, cancelled out by the buoyancy due to the water. They are also constructed so as to have a very large surface for the amount of matter they contain, which means that it is hard for them to be dragged through water by force from outside, but that they are easily carried from one place to another by the gentlest currents.

Now look again at figure 51. Do you notice how many of the plants, particularly towards the middle of the picture, have projecting spines (increasing their surface as in our tinfoil experiment). Notice too the absence of organisms shaped like spheres (with the minimum surface area). The majority look like long strands (in fact they are cylinders), some straight and others partly curved.

What you have read so far is not the whole story. The minute plants of the plankton can only exist in the upper few feet of the water where light can reach them. During daylight they produce bubbles of gas which make them less dense than the water. In the dark, plants cease to produce oxygen and that which is trapped inside them dissolves in the water. They become more dense than the water and cease to float. It is only because of the effect of their large surface that they sink so slowly that they do not go beyond the range of light penetration before the following day. Dead plankton slowly sinks to the bottom of the sea.

Finally, you may wonder how the animal plankton manages to stay in the same zone so that it can feed on the plants. If you look closely at figure 52, you will see that many of the animals are minute shrimp-like creatures and are able to move in much the same way as the large shrimps and prawns which you probably know. Very little of the animal plankton drifts passively like the plants. If we weigh a number of these small creatures we find that they are only just heavier than sea water. Also, like the plants, they have bodies with a large surface area which tends to stop them sinking. They maintain their position in the water with little effort. So we see that in spite of their small size they are beautifully adapted to exist in the area of their food without having to use up too much of it in providing energy for swimming.

Chapter 7

Movement in animals and plants

7.1 Movement in animals

From your own experience you will know that animals move about in many different ways. Some of them have legs – one pair (e.g. man), two pairs (e.g. a dog), three pairs (e.g. an insect), or many more (e.g. a centipede). If you have a chance, examine an animal such as a mouse and see how it uses its legs in movement. Other animals such as snails and worms have no legs and rely on changing the shape of their bodies in order to move. Water animals provide a good opportunity for observing movement.

If you look at small water animals swimming about you will see that some of them, such as insect larvae, seem to get along by wriggling, while others, such as flatworms, appear at first sight to move smoothly through the water. Fish seem to move quickly in a straight line. If you look down on a fish swimming in a pool or aquarium, can you detect exactly how it propels itself along? Does it paddle with its fins? What does its tail do while it is moving along? Can you see any movement of the whole body? If you look closely at the different sorts of aquatic insect larvae and fish, you should be able to see that they all bend their bodies into S-shaped curves when they are moving forward.

7.11 Muscles and movement in fishes

When eating cooked fish, you may have noticed that the flesh comes away in flakes. These flakes are portions of muscle. Let us examine a fish and see how the muscles enable the fish to bend its body in the way you have observed. You can use a herring or mackerel obtained from a fishmonger or any other fish which has been freshly killed.

1. Lay the fish on its side on a board.
2. Use a sharp knife or scalpel to remove the skin from the side of the body.
3. Cut away the surface tissues to show the muscles underneath which form the fleshy part of the body.
4. Make a drawing of a portion of the muscles on one side of the backbone.

5. Bend the fish by first raising its middle from the board and then raising its head and tail. Observe any changes in the blocks of muscle as you do this.

6. To see how the muscles are attached to the backbone, cut the fish in half thus separating the front part from the rear. The backbone itself is flexible and is bent into a curve when the muscles on one side contract.

We can see how this ability to bend from side to side helps the fish to move along by comparing the fish with various kinds of boats. The Japanese at one time made a boat with a joint in the middle which would be moved forwards by making the front and back halves flex alternately from side to side. Although this boat

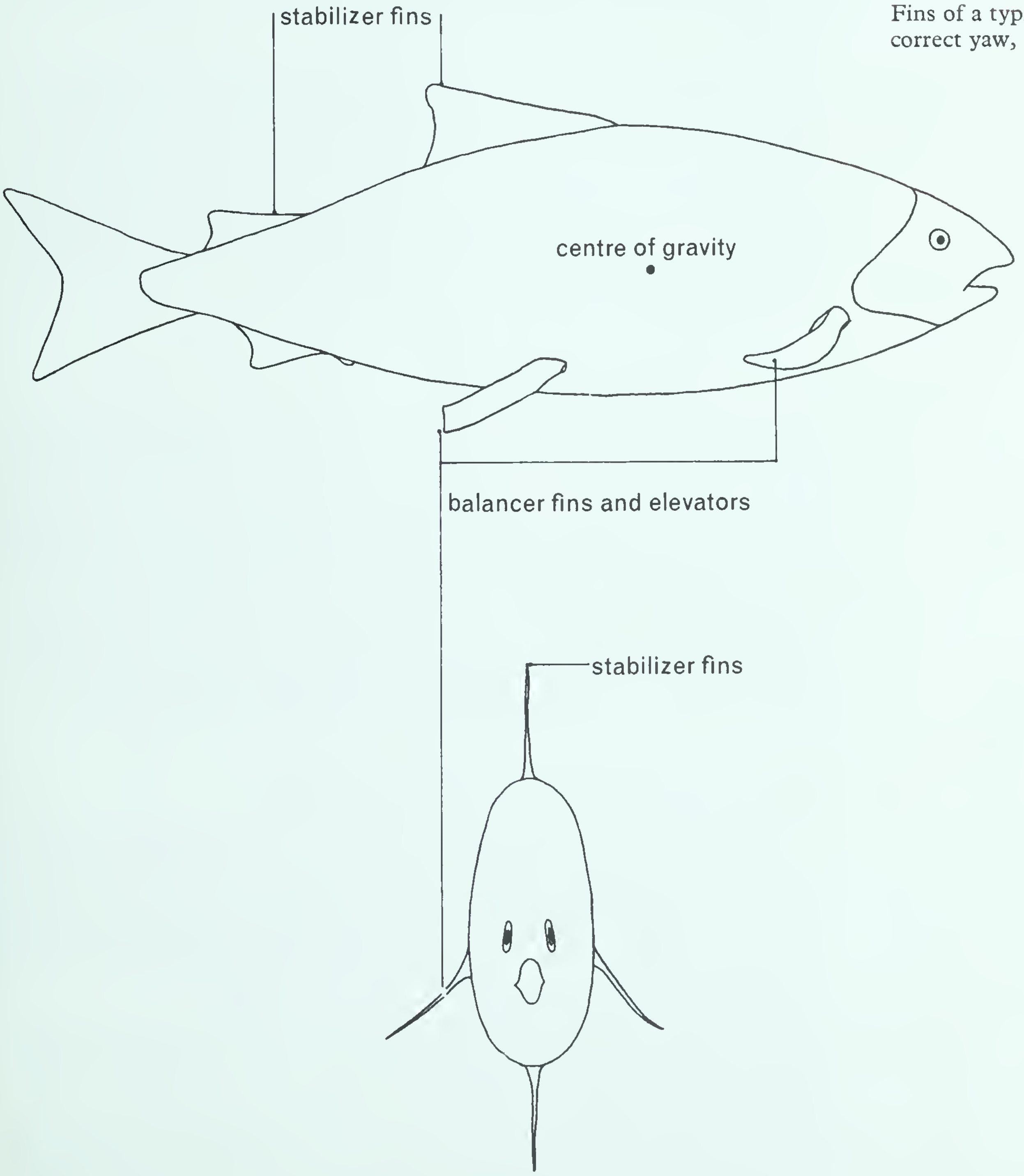


Figure 53
Fins of a typical fish. These help to correct yaw, roll, and pitch.

would move fast and efficiently, it was obviously not very practical for passengers or even for cargo. The nearest approach to such a method now in common use is the gondola used in Venice, or the small fishing boats which are propelled by one oar at the back which is moved from side to side. The oar is performing the same action as the hind part of the fish's body and tail. We shall see later just how this movement drives the fish or boat forward (section 7.12).

If you watch a boat being propelled in this way you will notice that it has a tendency to wander from side to side (to *yaw*) and also to rock from side to side (to *roll*). Tadpoles show similar movement from side to side when they swim using their tails. The keel of a boat helps to reduce these two movements. A fish similarly has fins along its back and underside which help to reduce yaw and roll.

Another uncomfortable motion of a ship, which happens in rough water, is known as *pitch*. This is when the boat see-saws. In big ships pitch is reduced by fitting stabilizers which project from the sides of the ship under the water. In a fish the fins, one pair at the front and one behind the centre, help to prevent it from pitching about in the water as it swims. Unlike the flippers of penguins and turtles, the fins of most fish are not used to paddle the animal along. See figure 53.

7.12 The use of the tail fin

You can quite easily devise a mechanical model to show the effect of the large muscles of a fish moving the body and tail fin from side to side (figure 54). This consists of a wooden body with a hole through the centre which houses an elastic band. The elastic is wound by turning the separate head of the model to which one end of the band is fastened. The other end of the band operates a wire cam which causes the tail to flap from side to side. The tail is made of flexible celluloid. Watch carefully what happens when you release the model in the water with the elastic fully wound.

7.13 Feeling the force of a 'fin' on water

If you put your hand and forearm into a bowl of water and move your hand from side to side you can imitate the action of a fish's tail. As your hand presses against the water so the water presses against your hand. Does this force of the water on your hand vary as you alter the angle of your hand in the water?

Observe fish in a pool or an aquarium, looking down on them from above. Look for the movements of the body and tail which cause the fish to move forwards. Ideally, you should see a slow-motion film of fish movement. It is difficult to see these movements in detail when the fish is swimming because they all happen so quickly. Even so, if you know what to look for you can probably just pick out the different stages.

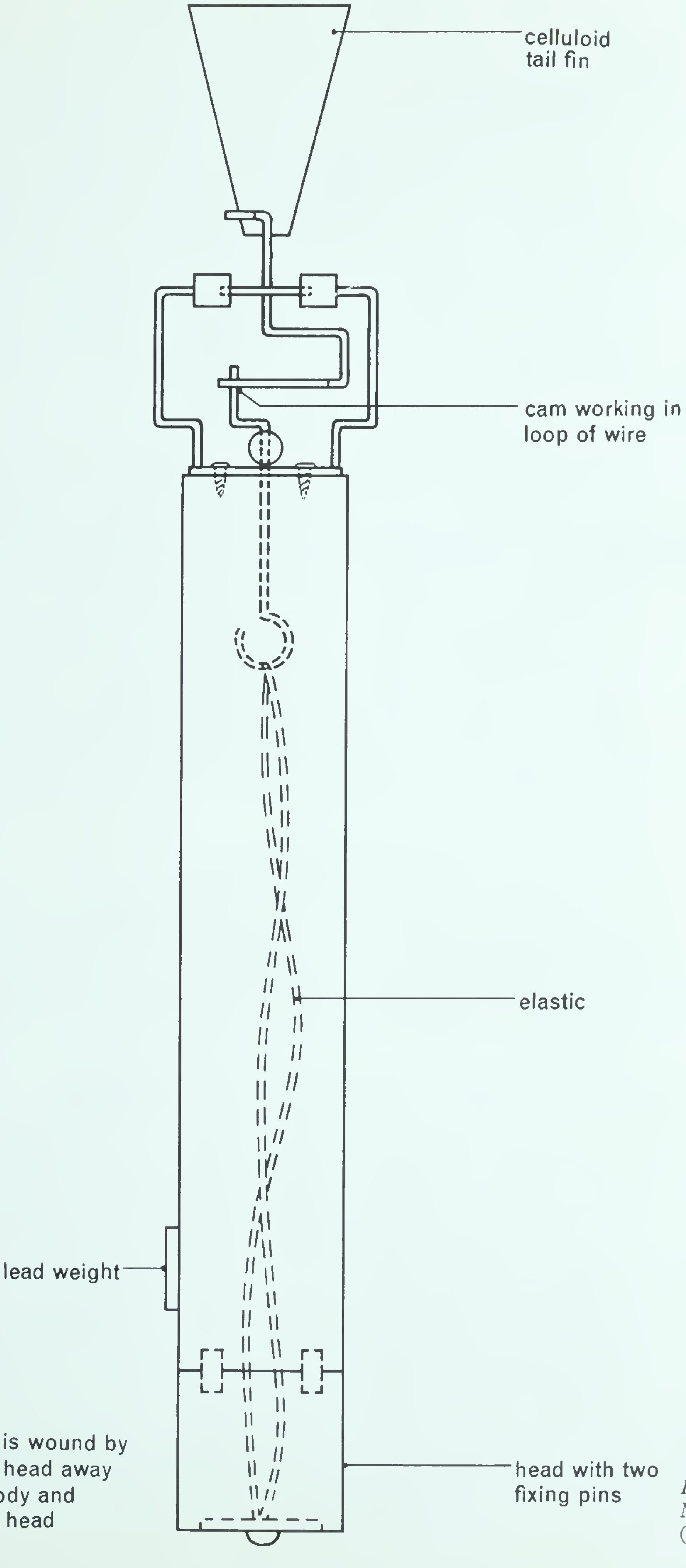

celluloid tail fin
cam working in loop of wire
elastic
lead weight
the elastic is wound by pulling the head away from the body and turning the head
head with two fixing pins

Figure 54
Model fish with a moving tail (scale full size).

7.2 Land animals and water animals

We saw in Chapter 5 that many land creatures gain extra support by having arched backs. The strong muscles of the back are used by animals not only in support but also in movement. Look at the series of drawings of a frog jumping (figure 55) and you will see how the muscles help in taking off and in landing. Watch a dog galloping, particularly a greyhound, and try to see what position the legs are in when the back is most arched. Do you think arching the back helps the animal to move more quickly? The cheetah shown in figure 56 shows similar movements.

Movement in these animals is different from that in fish and the other water animals that we considered earlier; although all of them use their back muscles when moving.

Let us now look at some mammals that live in water, such as whales, dolphins, and seals. They are faced with the same problems and difficulties as other water dwellers but are constructed much more like land animals. They move along by arching their backs rather than bending their bodies from side to side (figure 57), and you will notice that this up and down motion is assisted by a horizontal tail fin instead of the vertical fin in fishes.

Human beings use their back muscles less than most animals because they walk upright and therefore depend more for support and movement on their leg muscles. But what happens when human beings take to water? What swimming strokes depend for their efficiency on the strong back muscles and an ability to arch the back?

7.3 Movement in land animals

We walk by pushing our feet against the ground. So do horses, dogs, insects, and all other animals with legs. We also push when we ride a bicycle, trundle a wheelbarrow, or lift something above our heads. Let us examine how our muscles exert this pushing effort.

7.31 Muscles and movement in land animals

It is not easy to find out which muscle is responsible for a particular movement, but try this experiment on yourself.

1. Put several bricks or other heavy objects on a shelf behind you at shoulder height when you are standing or sitting.
2. Grasp each brick in turn, with your arm fully bent at the elbow.
3. Lift it by straightening your arm. The brick can be put on a higher shelf or taken from you by a partner. Your partner can also keep you supplied with bricks to lift.

There are two main muscles which cause the elbow joint to move – the bulging muscle in front called *biceps* and that at the back called *triceps* (figure 58). Which of these begins to ache when you push the bricks upwards by straightening your arm?

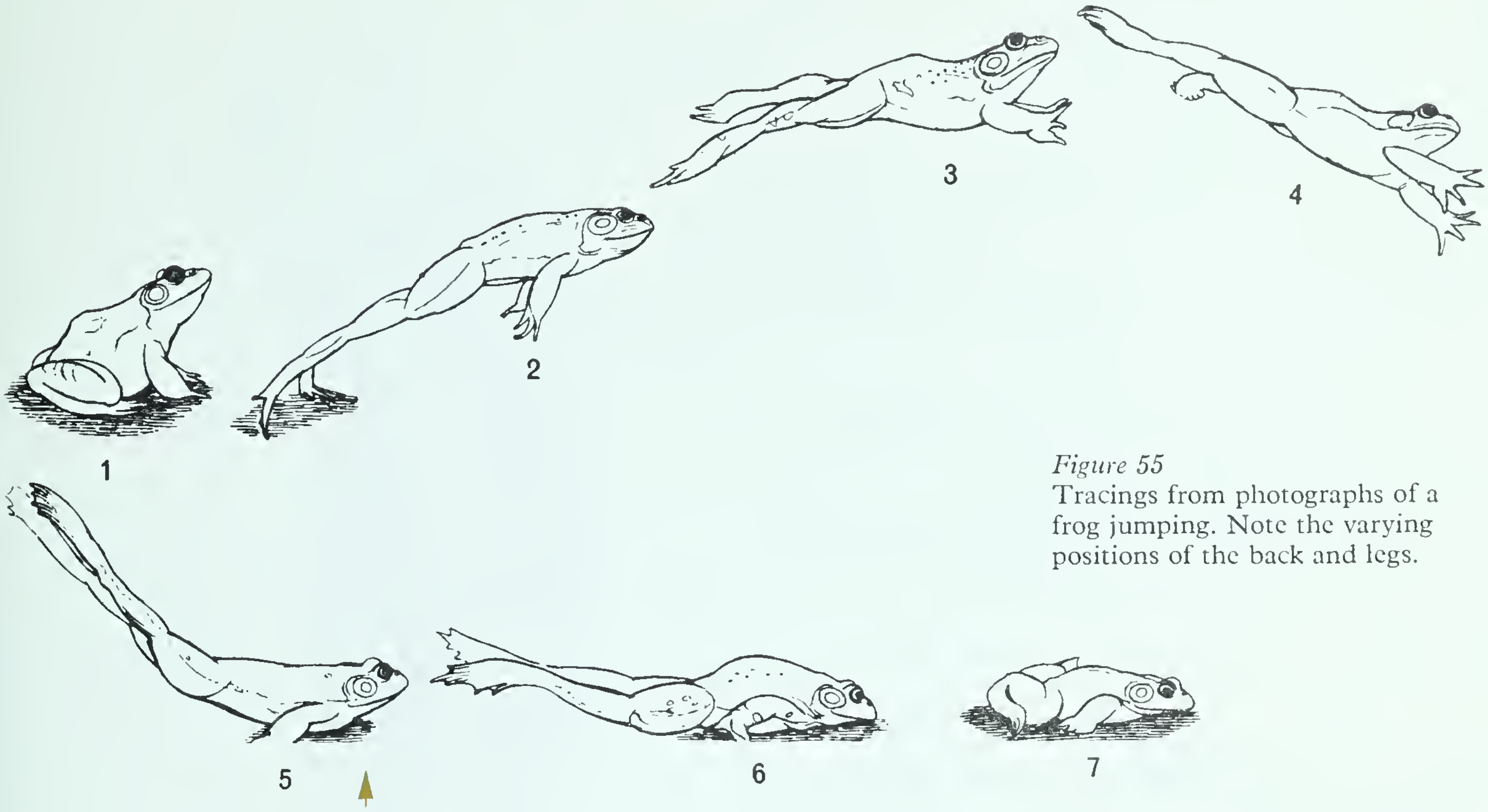


Figure 55
Tracings from photographs of a frog jumping. Note the varying positions of the back and legs.

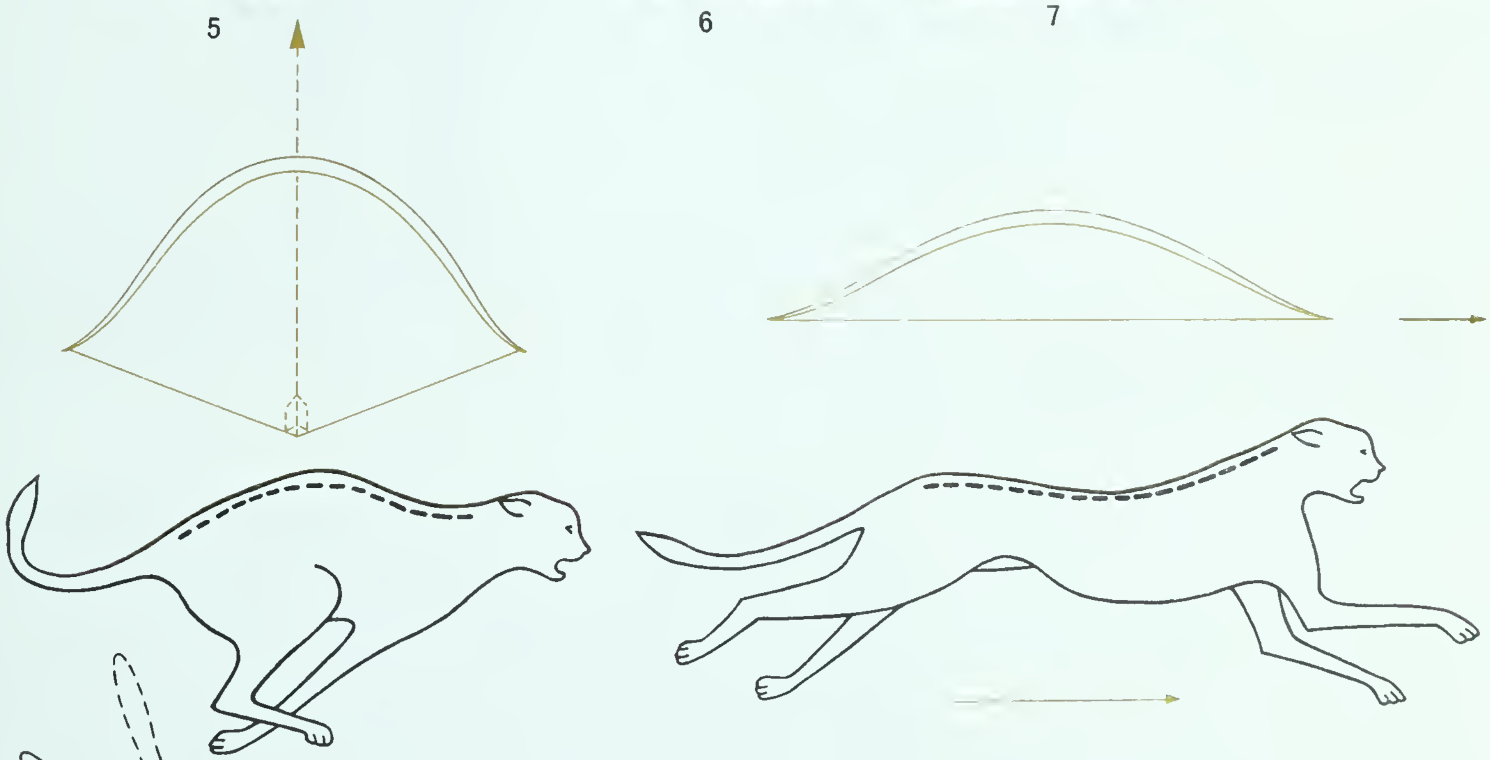


Figure 56
Use of back muscles in jumping and galloping.

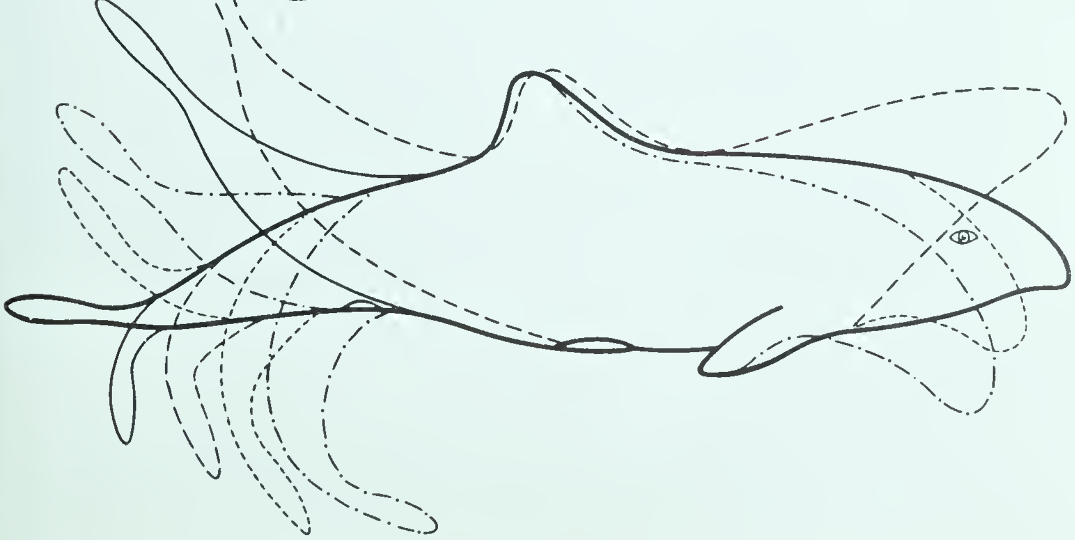


Figure 57
Flexing of the body of a whale. Note the different positions of the head and tail.

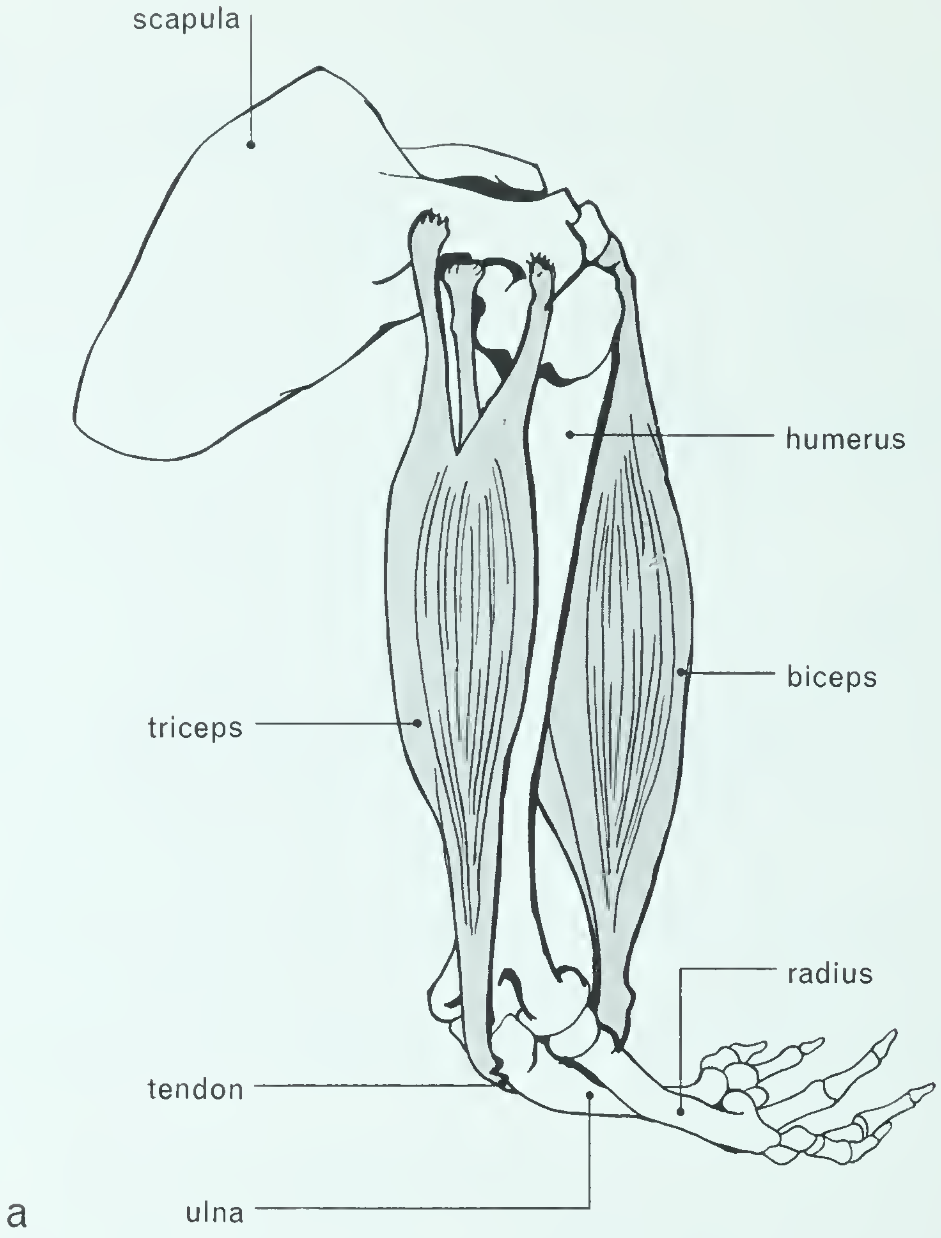
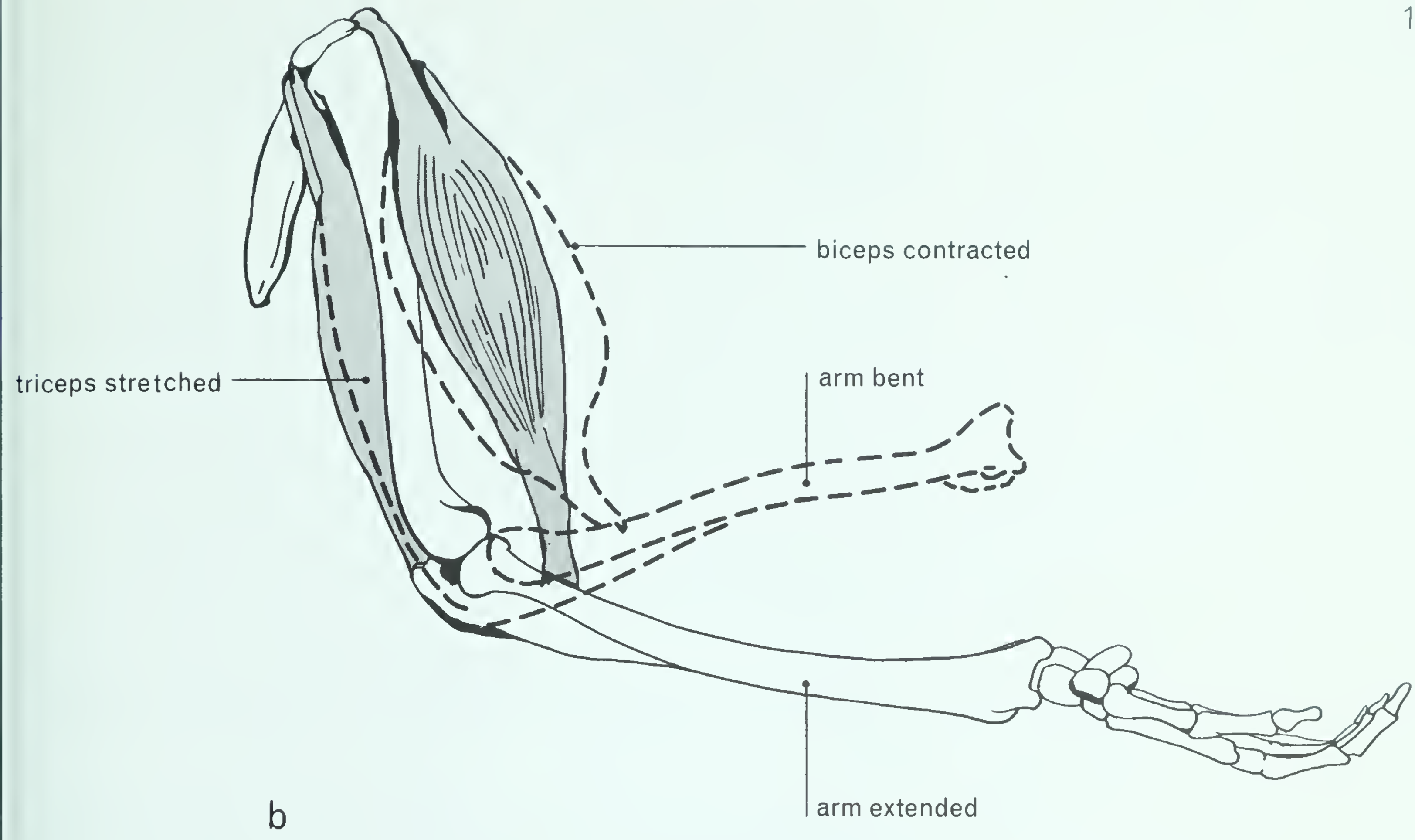


Figure 58
Diagrams of the elbow joint of man. Contraction of the biceps muscle causes expansion of the triceps and the reverse.

The bones of the forearm turn about the elbow joint, which acts as a pivot. The biceps muscle is attached to a bone in the forearm on one side of the pivot and the triceps to an extension of the bone of the forearm behind the pivot – the 'funny bone' as it is called. Joints always have at least two muscles to move them. When one muscle (in this case the biceps) contracts it causes the joint to bend and at the same time stretches the other opposite muscle (the triceps). When this second muscle contracts, it causes the joint to straighten and stretches the biceps. It is the contraction of the triceps muscle that provides the main pushing force when you straighten your arm. If you are in any doubt about the idea of a muscle contracting in order to move a bone you have only to observe your own biceps as you bend your elbow.

7.32 Muscles of the upper arm

You will be able to understand better how opposite pairs of muscles move bones by looking at a diagram of the bones of the arm with the muscles attached (figure 58).



Try making a model of the arm using strong cardboard or balsa wood for the bones and elastic or rubber tubing for the muscles. For a lifesize model lengths of cycle inner tubing make ideal muscles.

7.4 Cross-sectional area and the pull of muscles

We cannot unfortunately take out a living muscle and do experiments on it, so we must do the next best thing and find a model that resembles a muscle as closely as possible. Just as we used Plasticine when studying the strength and support of bones, so here we shall use elastic to study how muscles work.

You saw in section 7.31 how muscles always work in pairs. They cannot work alone, for though they can contract on their own, they cannot expand – something else must do that. Expansion can only come about by the pulling effect of other (opposite) muscles.

In our model, a piece of elastic when unstretched will correspond to a muscle which has contracted. The act of stretching the elastic corresponds to the pull of another muscle. If the elastic is now held at one end and let go at the other, the pull on the far end causing it to contract will be the same as that required to stretch it in the first place. When studying bones, you found that their strength increased in proportion to the cross-sectional area but decreased with length. Muscles vary greatly in size. Do the same principles apply to them as to bones?

We can use catapult elastic to imitate a muscle. Let us first find out how the strength of a 'muscle' alters with the cross-sectional area. Square section elastic is supplied in $\frac{1}{8}$ inch, $\frac{3}{16}$ inch, and $\frac{1}{4}$ inch. A convenient length to use is 20 cm between the points of attachment.

1. Cut about 25 cm of each gauge elastic.
2. Make firm ties with thin string at the ends of each piece of elastic so that the length between the ties is exactly 20 cm.
3. Using the thinnest gauge of elastic fix one tie to a clamp at the bottom of a retort stand and the other to the hook of a 0–100 g spring balance held in the upper clamp.
4. Place a ruler alongside the elastic and check that when the spring balance reads 0 the distance between ties is 20 cm.
5. Raise the upper clamp holding the spring balance until the distance between ties is increased to 25 cm by stretching the elastic (see figure 59).
6. Read the spring balance and enter your results in a table similar to table 1.
7. Repeat the experiment for each of the other pieces of elastic, changing the spring balance when necessary to one giving a higher reading.

Remember that the force you have measured by the reading of the spring balance is that required to stretch the elastic from 20 cm to 25 cm. It is reasonable to assume that this is the same force which a muscle would exert when contracting from 25 cm to 20 cm.

Diameter of elastic	Ratio of cross-sectional areas	Pull in g when extended from 20 cm to 25 cm
$\frac{1}{8}$ in	4	
$\frac{3}{16}$ in	9	
$\frac{1}{4}$ in	16	

Table 1.

From the results you recorded in table 1 answer the question 'Is the pull of a muscle proportional to its diameter or to its cross-sectional area?'

7.41 Muscle contraction and change of volume

With the thin elastic you have been using, it is difficult to make measurements which show changes of the cross-sectional area as the elastic is stretched. You can do better by using the catapault elastic of square cross-section and $\frac{1}{4}$ inch diameter. Measure the

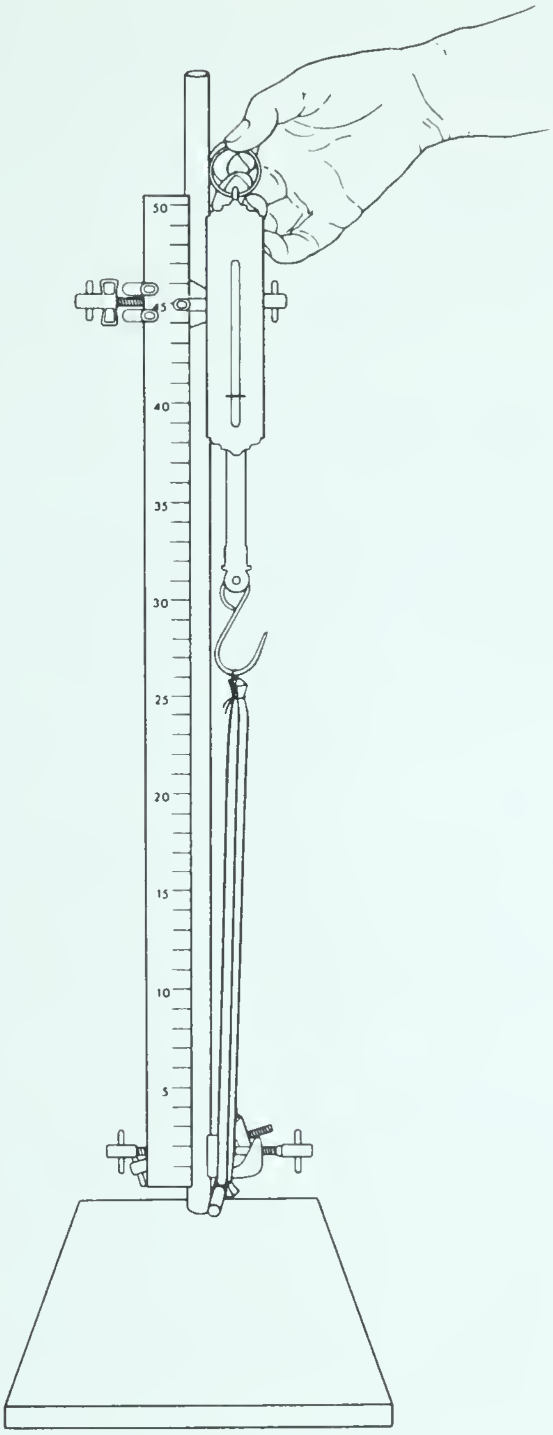


Figure 59
Apparatus to record the pull of an elastic 'muscle'.

width of the elastic in centimetres. To make your job easier a width gauge is needed. You can make one for yourself, in Perspex or cardboard, similar to that shown in figure 60.

1. Stick two pins through the elastic so that their points are exactly 10 cm apart.
2. Check that the elastic will just fit the 0·6 cm slot to the gauge, as shown in figure 60, when the pins are 10 cm apart.
3. If the elastic is wider than 0·6 cm, pull it out until it just fits the gauge and measure the distance between the pins. Record in table 2.
4. Pull out to fit the 0·5 cm slot and measure the new length.
5. Repeat for the 0·4 cm slot.
6. Calculate the volume in each case. (Multiply the length width × width.)

Diameter (width of slot in cm)	Length (in cm)	Volume length × width × width in cubic cm (cm^3)
0·6		
0·5		
0·4		

Table 2.

7.42 Length and pull of a muscle

The different muscles of the body vary greatly in their length. Similar muscles in different individuals also differ in length. Is the pull which a muscle exerts affected by its length?

For this experiment use a single length of about 55 cm of the thin gauge elastic.

1. Place string ties on the elastic near one end and at 10 cm intervals along it.
2. Stretch the first 10 cm length by one quarter of its length to 12½ cm using the apparatus as set up in figure 59. Record the reading of the balance as in table 3.
3. Repeat using a 20 cm length of elastic stretched to 25 cm.
4. Repeat for the other lengths up to 50 cm.

Original length	Extended length	Pull in g
10	12·5	
20	25	
30	37·5	
40	50	
50	62·5	

Table 3.

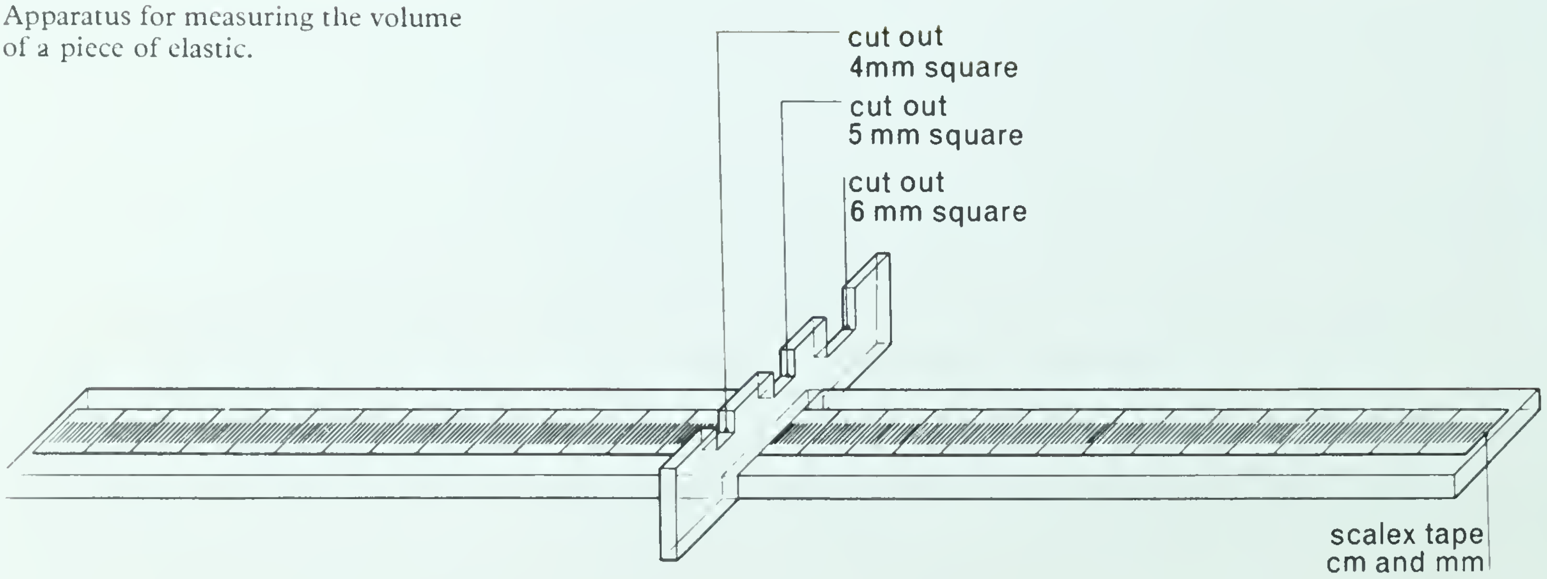


Figure 60
Apparatus for measuring the volume of a piece of elastic.

Do you notice any increase in the pull required to stretch the longer elastic compared with the shorter? The results in the final column of the table should enable you to answer the question, 'Can a long muscle exert more pull than a short muscle of the same thickness?' You will have noticed that most animals which are fast runners or good jumpers have comparatively long legs, and therefore long muscles. If a longer muscle can exert no greater force than a short one, what is its advantage?

Look again at your table of results and see how far you had to move the spring balance in order to extend each piece of elastic by one-quarter of its length. The distance you had to move the hook of the spring balance in stretching the elastic represents the distance through which the pull acts when the 'muscle' contracts.

These experiments with models lead us to an important conclusion concerning the ways in which we can compare the action of one muscle with that of another. It is not enough to measure just the 'pull'; we must also know the *distance* through which that pull acts. If we multiply the force by the distance – we obtain what is known as the *work* done by the muscle.

You have found in Chapter 5 that if the length and width of an animal are doubled, its weight increases eight times. When an animal jumps the work done by the muscles is used up in lifting its own weight off the ground. The best jumpers are therefore those animals that combine a light body with long powerful muscles – like the cheetah (figure 56) for example.

We have seen that the 'pull' of a muscle depends upon its cross-sectional area, but the work it does depends both on the cross-sectional area and length. Thus doubling the length and width of a muscle will produce eight times as much work. So you can see that doubling the dimensions of an animal increases its weight eightfold but provides muscles capable of eight times the amount of work. This should mean that the height to which an animal can jump is the same whether it is small or large.

Animal	Height of Jump (ft)	Length of Jump (ft)
Deer	8–10	
Elk	8–10	
Impala (gazelle)	8–10	30
Kangaroo	9	25
Kangaroo mouse	5	10
Cat	8	
Frog	5	16
Lion	8–10	
Man	7	27

Table 4.

What conclusion can you draw from the figures given in table 4 about the relationship between the size of an animal and the height to which it can jump? Compare the heights reached by a frog, cat, and man.

Differences in jumping performances are due to other factors than the weight of the animal and the work done by the muscles. The lengths of the legs of large animals are not proportional to their size for reasons of support, as you discovered in Chapter 5. The elephant has legs which are thicker but shorter in proportion to its size than those of the dog. The muscles of an elephant exert enough 'pull' to lift its weight, but their short length cannot produce the power to enable the animal to leave the ground. It usually lifts only one of its legs at a time.

At the other end of the scale, in very small animals, air resistance may prevent the animal from reaching the height we would expect it to be able to jump.

The arrangement of the muscles also varies considerably from one animal to another. Muscles for running, flying, or swimming are not likely to give the best performance in jumping.

We often compare animals and plants by saying that animals move about whereas plants stay in one place. While it is not strictly true to say that plants cannot move, it is true that they possess nothing in their make-up resembling the muscles of animals. What sort of movements do plants make?

7.5 Sleep movement of plants

A very simple experiment using tulips will show one kind of movement. It is essential to have freshly cut tulips which have not opened before, and with the flowers still closed. Keep the stems of the flowers in water.

1. Place one flower in a cool, dark place (an outhouse, food cellar or pantry or – failing any of these – in a refrigerator).
2. Put another flower in a well lit position in a warm room.
3. Observe for a period of several days, the state of opening of these two flowers (*a*) early in the morning, (*b*) at noon, (*c*) late afternoon.
4. During a period of about an hour find out what happens (*a*) when you bring the flower kept in a cool, dark place into the light, (*b*) when you bring the fully opened flower from the warm room into the cool, dark place.

You can observe movements similar to those of tulip petals, in daisy flowers which close at night, and also in the leaves of certain plants. Thus the three leaves of clover or sorrel fold back alongside the stem at night. Rather slow and reversible movements of this sort are called 'sleep movements'. A much quicker sort of movement can sometimes be caused by touching the leaf, as in the sensitive plant *Mimosa pudica*, which you can easily grow from seed in a greenhouse.

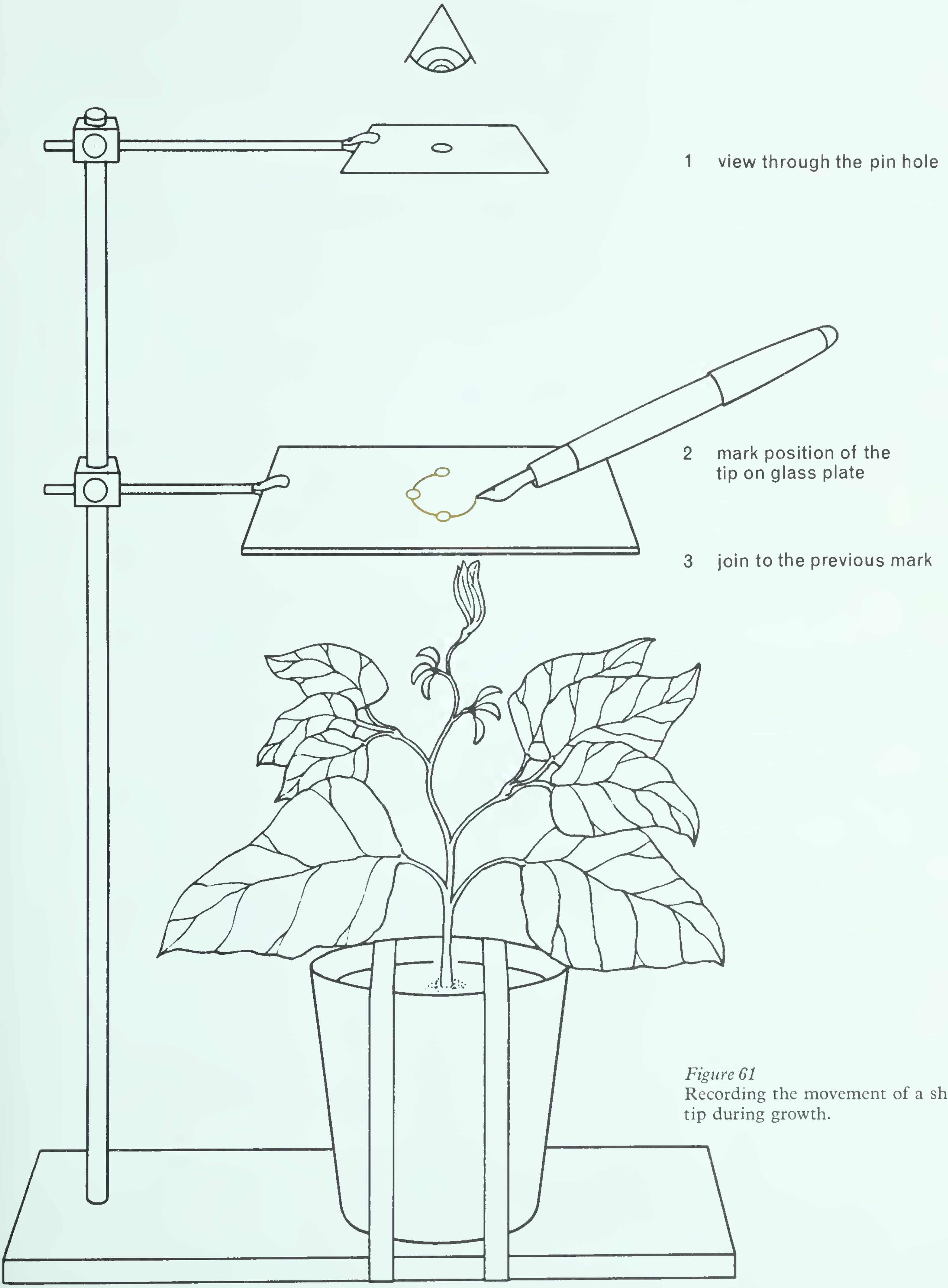

1 view through the pin hole
2 mark position of the tip on glass plate
3 join to the previous mark

Figure 61
Recording the movement of a shoot tip during growth.

7.51 Movement of shoot tips during growth

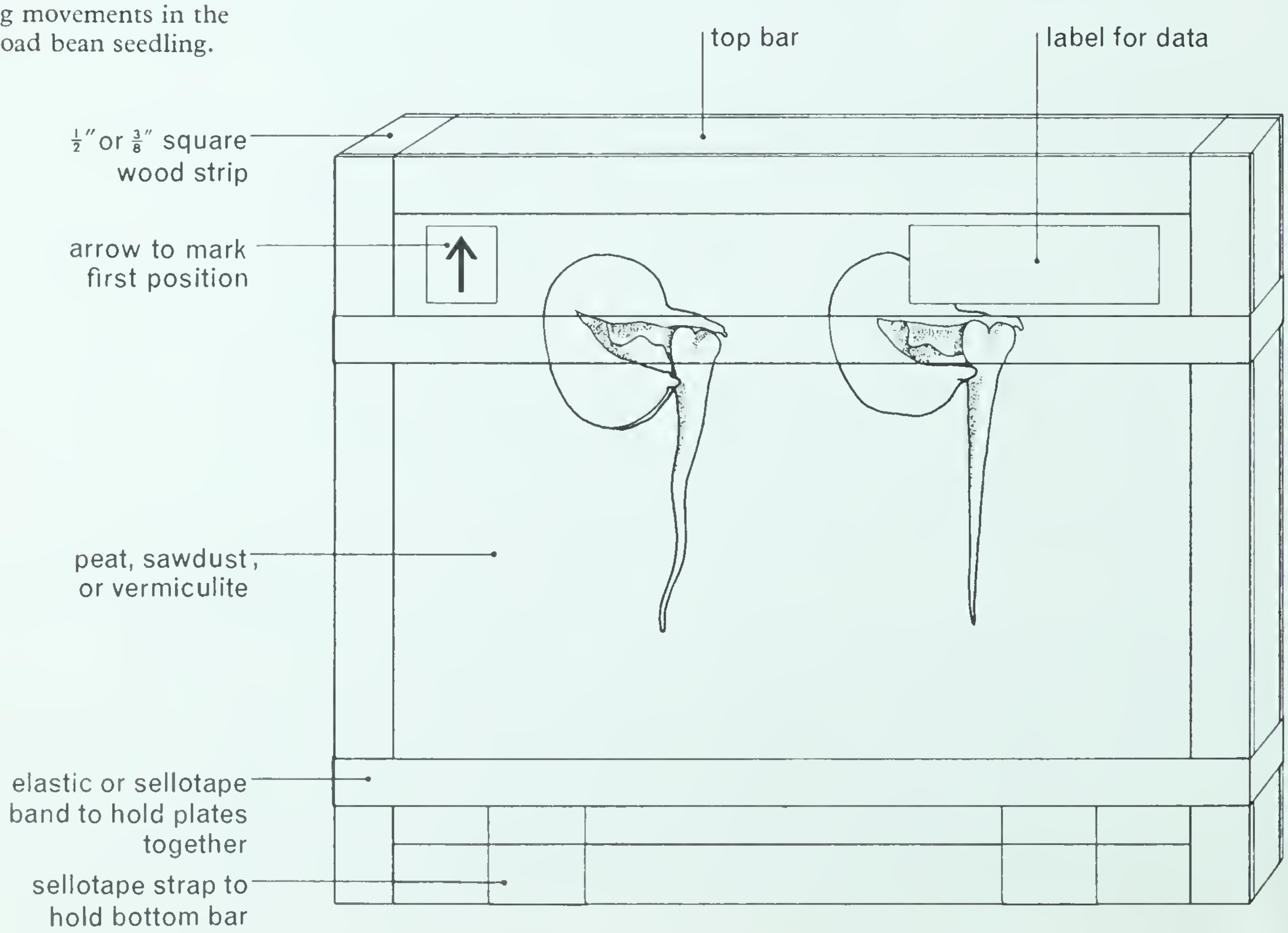
Many other movements of plants take place so slowly that they cannot be observed directly. We may only be aware that movement has taken place when we keep records or note the position of a part of the plant at intervals of several hours or days. These movements are due to growth in different directions.

To show one sort of movement of this kind use a runner bean seedling in a pot.

1. Fit the pot to the base of a retort stand using two elastic bands so that the plant cannot be accidentally moved.
2. Clamp a glass plate horizontally a few inches above the tip of the shoot.
3. Fasten a square of cardboard near the top of the retort stand directly over the glass plate.
4. Make a small hole through the centre of the card (figure 61).
5. At convenient times – before school, break, lunchtime, and after school – peep through the hole and put a mark on the glass plate where the shoot tip appears to be.
6. Join each mark as you make it to the previous one. The line on the glass plate will give you a rough idea of the movement of the tip of the runner bean as it grows.

Do all the beans used in your class move round the same way and, if so, is the movement as seen from above clockwise or anticlockwise?

Figure 62
A germination sandwich for investigating movements in the root of a broad bean seedling.


top bar
label for data
$\frac{1}{2}$″ or $\frac{3}{8}$″ square wood strip
arrow to mark first position
peat, sawdust, or vermiculite
elastic or sellotape band to hold plates together
sellotape strap to hold bottom bar

This type of movement is most noticeable in climbing plants. It enables them to find a support and twine around it. But the tips of plants which do not climb also show the same kind of movement, and this takes place even when the plants are grown for a time in the dark. Can you devise a simple way of investigating this?

7.52 Growth movements in a broad bean plant

You may also have noticed another kind of movement in plants. What happens to the direction of growth of a shoot when a plant is blown over, or when you have a plant in a room where light comes only from one side?

This type of movement occurs in roots as well as in stems. To investigate it you can grow broad bean seeds in peat between two sheets of glass.

1. Fit two pieces of clean glass about 6 × 5 inches held apart by strips of wood $\frac{1}{2}$ inch wide placed along each side of the glass sandwich (figure 62).
2. Fill the space between the plates with wet peat.
3. Place several soaked broad bean seeds in the peat.
4. Fasten the sandwich together by elastic bands or Sellotape. The sandwiches are best stored like books on a shelf but it is important to see that the same edge is always uppermost.
5. Mark the wooden strip TOP or stick a label to the glass with an arrow drawn to indicate which end is the top. The beans should germinate in one or two weeks.
6. Choose one seed with a good root and shoot and make a drawing of it showing the exact position and length of both root and shoot.
7. Turn the sandwich through 90° so that the edge which was top is now one of the sides.
8. After several days observe the seed of which you have the drawings and note the length, shape, and direction of growth of the root and shoot.

Now try to answer the following questions:

a. In which direction do roots and shoots grow in the bean seedling?
b. Does any part of a root which has already grown bend when a seedling is turned through 90°?
c. In what direction does further growth of the root of the turned seedling take place?
d. If, after a period of growth in the turned position, the seedling is returned to its first position, do you think the root would become straight again?

From your observations, would you say that plants can move and grow to suit themselves to a number of different positions?

Summary

In vertebrate animals, muscles are used to move bones. Water animals with a backbone use their powerful muscles to bend the body and tail in swimming.

Muscles are arranged in opposing pairs; each muscle can only do work by contracting.

The pull of a muscle is proportional to its cross-sectional area, so that doubling the diameter of a muscle increases its pull four times.

But the pull is independent of the length of the muscle.

The work done by a muscle, however, increases with its length. Although the pull exerted by a long muscle is no greater than that of a short one, it can act through a greater distance. This distance increases in proportion to the length of a muscle.

The work done by a muscle
= the force (pull) × the distance through which the pull acts

Most plants cannot move about freely like animals. Such movement as does occur in plants usually involves bending and is not due to muscles.

Many plants move in response to a stimulus such as light and show sleep movements, or close up when touched.

The tip of a plant shoot moves in a spiral as the plant grows.

Most plant movements result from a change in the direction of growth.

Background reading

Movement in water

Do you remember the first time you bathed in the sea or in a swimming bath and tried to swim on your own? For some of you this experience may be still to come. When it does you may perhaps remember reading the few pages that follow.

Most land animals when they find themselves in water try to keep afloat and to move along by ways very similar to those they employ on land. Next time your dog plunges into the water to retrieve a stick watch how he swims. He paddles hard using all four legs as he does when running. When we first try to swim we behave in a similar way to our dog. We imitate the natural crawling movements which all small children use before they can stand up.

Very early in man's history, he must have observed frogs and toads swimming in water just as you may have done. Our own species show this movement well, but the African clawed toad (*Xenopus laevis*), which is well worth breeding in a school laboratory, shows it even better. Perhaps this is not surprising as the animal spends the whole of its life in water. In swimming, frogs and toads make use of two movements which take place together. The arms are pushed forwards and then swing sideways as far as they will go. The elbows then bend and the arms are pushed forwards once more. Meanwhile, the hind limbs are thrust out-wards and backwards. The legs are brought forwards again by bending the knees. Both these movements serve to produce the same result. They push the water surrounding the body backwards and, as a result, there is a forward movement. Try imitating the movements of a frog while lying on your stomach. It will remind you of your first swimming lesson, for you will be doing the familiar breast stroke. If you examine the hind limb of a frog you will see that its toes are joined by webs of skin and this helps to increase the amount of water that it can push backwards at each stroke. Man has now imitated the frog in producing rubber flippers which are always worn by skin divers and which you can use too if you want to swim faster.

Man must have been aware of the movements of water animals, such as the fishes and whales which we studied in the last chapter. Perhaps it was from these that he obtained the idea of swimming by moving his legs rapidly up and down, much like the movement of the tail in a dolphin or whale. In this stroke the arms help by means of a paddle action a little like that of a dog's paws, except that the arms are brought forward again at the end of each stroke by bringing them right out of the water and over the head in a bowling action. These leg and arm movements combined have given us one of the fastest means of moving through the water that man has yet achieved – the crawl stroke.

The devices used by animals for moving in water are far more varied than the swimming strokes of man. Next time you go to a zoo, visit an aquarium and see for yourself. Take a notebook with you and record as many different methods of movement as you can find. Some of the fastest movers are not vertebrates at all. Large molluscs such as the octopus and squid move when alarmed by a method of jet propulsion, and squirt out a cloud of black 'ink' at the same time – a kind of 'smoke screen'. They are most exciting to watch.

But not all animals living in water are fast movers – far from it. If you watch a garden snail sliding along you will see that it makes use of a large, muscular 'foot' which is covered with slime. The slime helps in gripping the ground, and the animal moves because the muscles of the underside of the foot expand and contract to produce a rippling motion.

The various water snails move in the same way. Molluscs with two shells (bivalves) such as oysters and mussels also have a foot which is shaped like a wedge and pushed out between the two shells when they are slightly opened. The animals move by driving the foot into the mud in which they live and then, using the foot as an anchor, pulling the body on to it. You might imagine that progress by this rather laborious means would be a slow affair – and you would be right. The large freshwater mussel (*Anodonta cygnea*), which lives in ponds, grows to a length of six inches, and has been estimated to move at the stately rate of about a quarter of a mile a year.

Some animals are faced with a double problem of living part of their lives on land and part in water. Turtles for instance spend most of their life in water but, being reptiles, they must come on land to lay their eggs. Their legs are developed into excellent paddles which they use for swimming but these are no longer much use for walking. As a result, the animals make very heavy weather of going even the short journey up a beach to lay their eggs. Seals, too, have limbs modified as flippers for swimming and they also find movement on land a difficult operation. Among birds, penguins have lost all power of flight but can use their wings as flippers and are extremely agile swimmers. So we see that, as we might expect, organs used in swimming are far less effective when used for movement on land. Similarly, our legs which serve us so well on land are no match in swimming with the flippers of a penguin.

Chapter 8

How plants reproduce and make seeds

8.1 Introduction

Animals grow from eggs after they have been fertilized by sperms; but what happens in plants? To answer this question we must find a plant which produces flowers and have a closer look at the flower itself.

8.11 Finding the different parts of a flower

Select any reasonably large garden or wild flower belonging to the wallflower family (Cruciferae). It need not necessarily be like the one illustrated in figure 63.

1. Choose one of the flowers in which the petals have just opened out.
2. Using the drawing in figure 63*a*, find the *sepals* and *petals*.
3. Remove all the sepals and petals one by one.
4. Using the drawing in 63*b*, find the six stamens. There are two outer ones and four inner ones.
5. At the base of each of the outer stamens you may be able to make out a swelling. This is the *nectary*. Break one of the nectaries with a needle and taste the contents. Can you detect a familiar taste?
6. With a hand lens look at one of the stamens. It consists of two parts – the stem or *filament* and the head or *anther*. Take off the six stamens and put them in a watch-glass.
7. Examine one of the stamens with a hand lens. Make a drawing of what you see. How many lobes can you find on the anther head? Is it covered with tiny round grains? Figure 63*c* shows an older flower in which the sepals, petals, and the two outer stamens have been removed, leaving the four ripe inner ones.
8. Now examine the tall structure in the middle. This is the female part of the flower. Find the ovary and the *stigma* at the end of the short *style*. Draw the whole structure.
9. Lower down the flower spike you will find flowers from which the sepals, petals, and stamens have dropped, leaving the female part of the flower intact. Choose one of these structures and with a scalpel cut it into two, lengthwise. Look at figure 63*d*. Can you see the row of *ovules* down the middle?

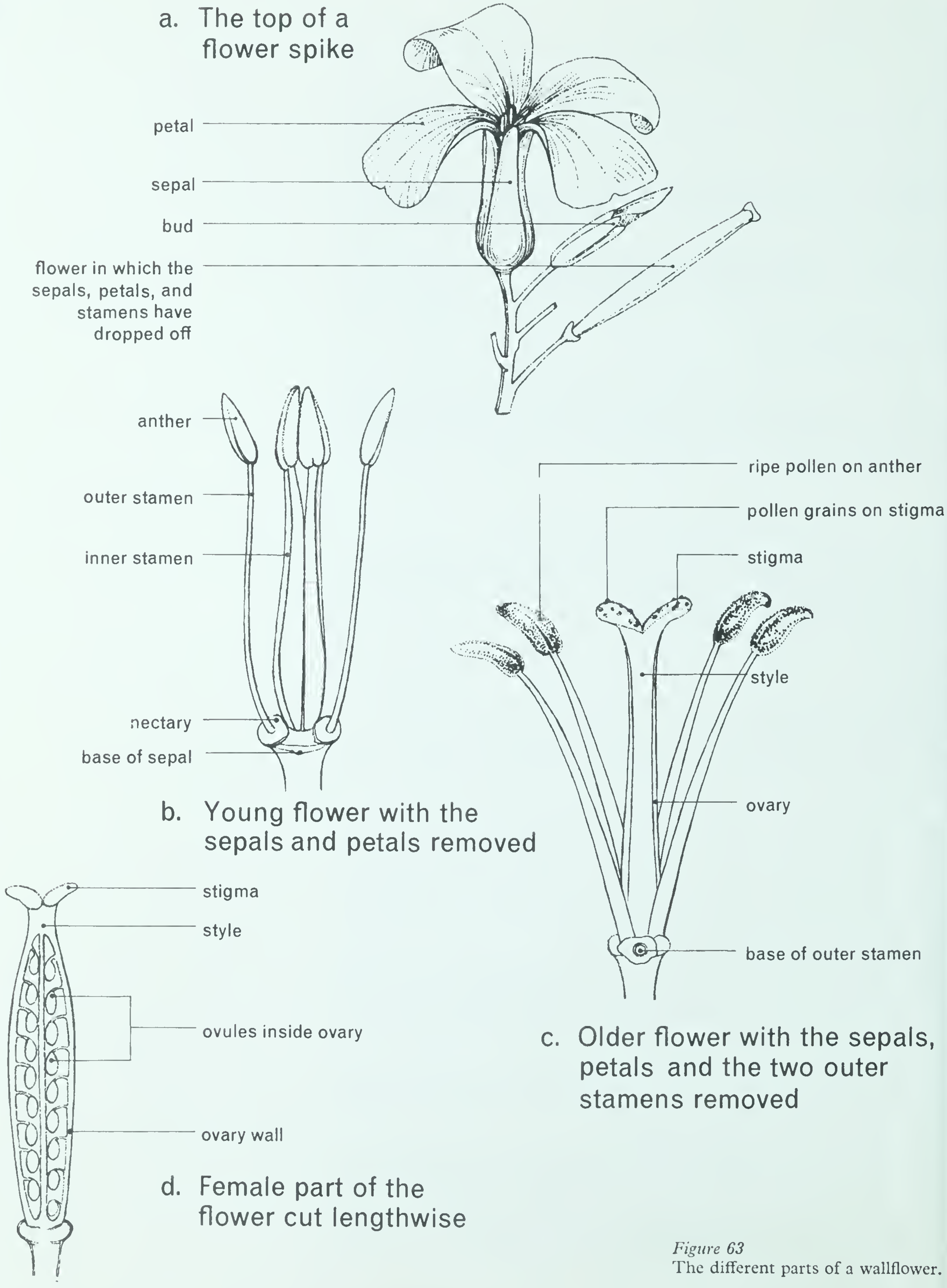

a. The top of a flower spike
petal
sepal
bud
flower in which the sepals, petals, and stamens have dropped off
anther
outer stamen
inner stamen
nectary
base of sepal
b. Young flower with the sepals and petals removed
ripe pollen on anther
pollen grains on stigma
stigma
style
ovary
base of outer stamen
c. Older flower with the sepals, petals and the two outer stamens removed
stigma
style
ovules inside ovary
ovary wall
d. Female part of the flower cut lengthwise

Figure 63
The different parts of a wallflower.

The ovules are structures that contain the egg cells of the wallflower which correspond to the eggs produced by a female animal. They grow inside the ovary. The whole structure in the middle of the flower, consisting of ovary, style, and stigma, is the female part of the flower.

The round grains growing on the anthers are pollen grains. These contain the male cells which correspond to the sperms produced by a male animal. The stamens together form the male part of the flower.

8.12 Examining the bud of a flower

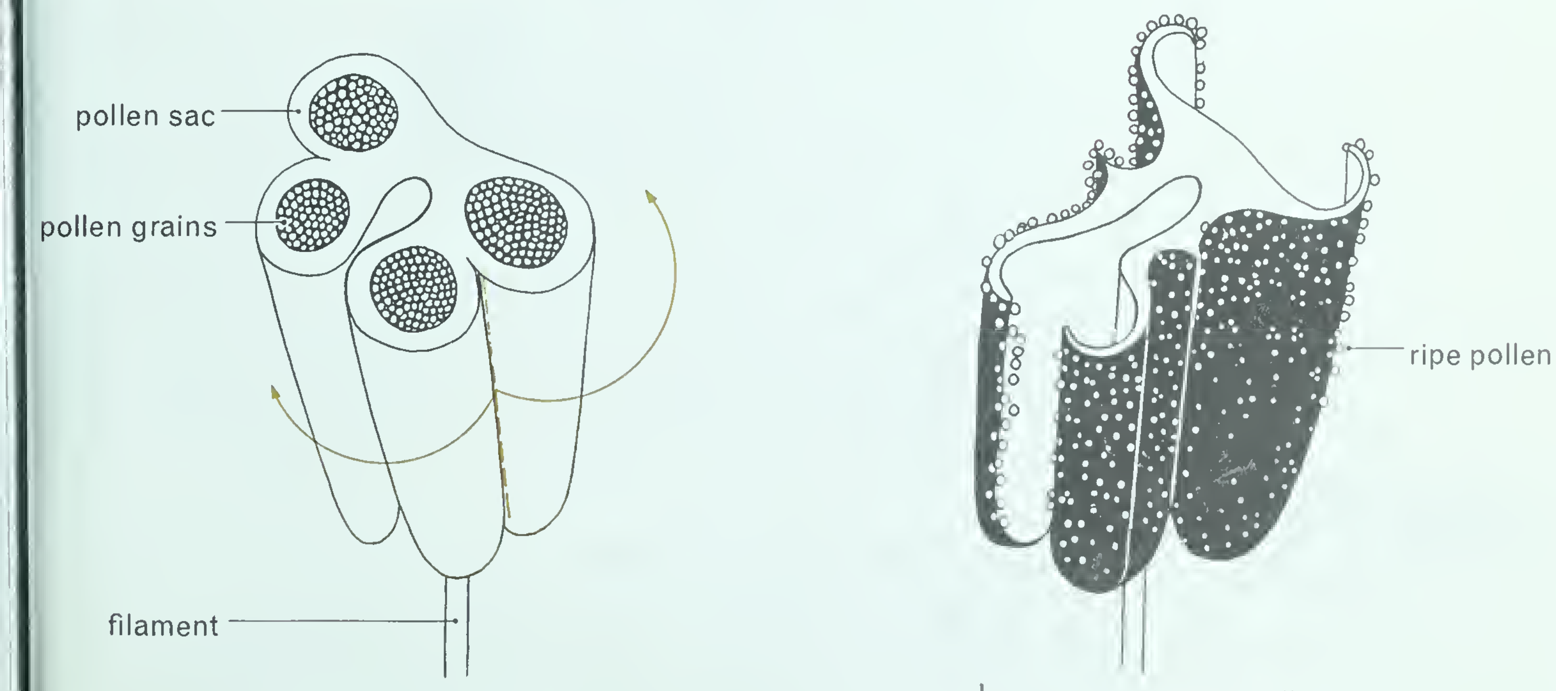
In taking off the stamens you will probably have found that pollen fell out of them. This shows that they were ripe.

1. Select a flower bud that is not open.
2. Remove the sepals and petals as you did before, and then one of the stamens and put it on a watch-glass.
3. Examine the stamen. Can you see any pollen grains on the anther, or is it still covered with a skin? If so, the pollen is not yet ready to be shed.

8.13 The anthers and pollen ripen

If you examined the stamens inside the bud of the flower (section 8.12) you may have found that the anthers had not burst and that you could not see any pollen grains. Figure 64*a* shows an unripe anther from a flower, cut across. It has four sacs in which the pollen grains are packed tightly. Figure 64*b* shows the same anther when it is ripe. The walls have burst and the ripe pollen

Figure 64
An anther with the top cut off.



a Unripe anther from a flower in bud

b Ripe anther with pollen sacs split and ripe pollen grains are now clinging to the walls of the pollen sacs which have turned inside out. The pollen is ready to leave the anthers. Not all flowers have stamens with anthers that burst in this way.

1. Find a flower with large stamens and anthers such as a tulip.
2. Cut an unripe anther across and examine the pollen grains inside with a hand lens.
3. With a lens examine a ripe anther and see if you can find out how it has burst.

8.14 Examining different kinds of pollen

Are pollen grains from different kinds of flowers all the same size, shape, and colour? You could try examining pollen from other flowers, either wild or from the garden. During summer and early autumn you should have no difficulty in finding suitable flowers. In the spring try bluebell (*Endymion non-scriptus*), primrose (*Primula vulgaris*), dandelion (*Taraxacum officinale*), tulip, or one of the trees with catkins – alder (*Alnus glutinosa*), pussywillow (*Salix caprea*), or hazel (*Corylus avellana*).

1. Shake some pollen from, say, a bluebell onto a slide and look at it under a binocular dissecting microscope.
2. Shake pollen from other flowers (pussywillow, dandelion, primrose, tulip, or alder) in turn onto microscope slides. Focus under low power and note the colour of each kind of pollen against the name of the flower.

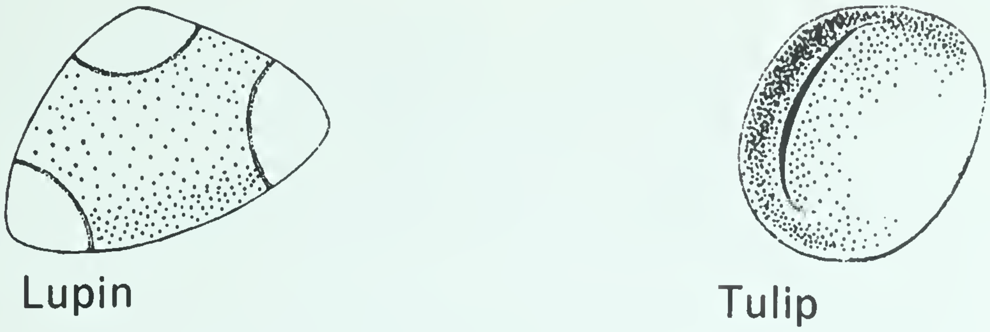
You have been looking at pollen grains under low power but if you increase the magnification and look at the grains under high power (magnified about 400 times) you should see their structure much more clearly.

Look at these different kinds of pollen focused under the high power of the microscope. You will see their shapes better if you hold a pencil just above the mirror to cut out some of the light.

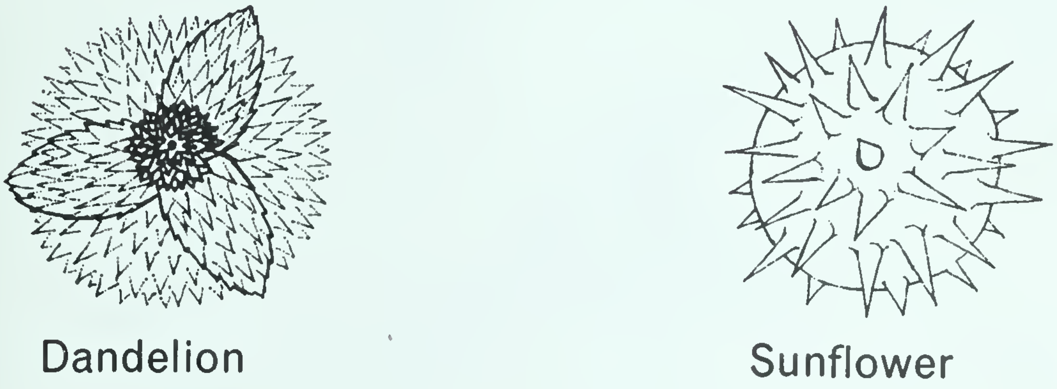
The drawings in figure 65 show some pollen grains from different flowers. In some flowers such as the crocus or tulip the pollen is round and smooth. Pollen from sunflower, cucumber, and dandelion, however, is rough and covered with spikes, while pollen from catkins or from pine trees is smooth and has air-filled wings. Figure 70 shows photomicrographs of the pollen grains of mallow (*Malva sylvestris*) covered with spines, and a pollen grain of the black pine (*Pinus nigra*) which has two air-filled sacs.

8.15 Insects and flowers

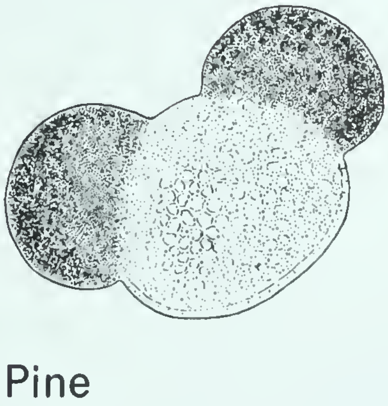
You have probably noticed that flowers are frequently visited by all kinds of insects, including small flies, bees, beetles, moths, and butterflies. By shaking a dandelion or sunflower in the palm of your hand, you may find that several insects will fall out.



a The grains are smooth and sticky so that they easily adhere to the hairs on the insect's body



b The grains are covered with spikes which help them to cling to the hairs on an insect's body

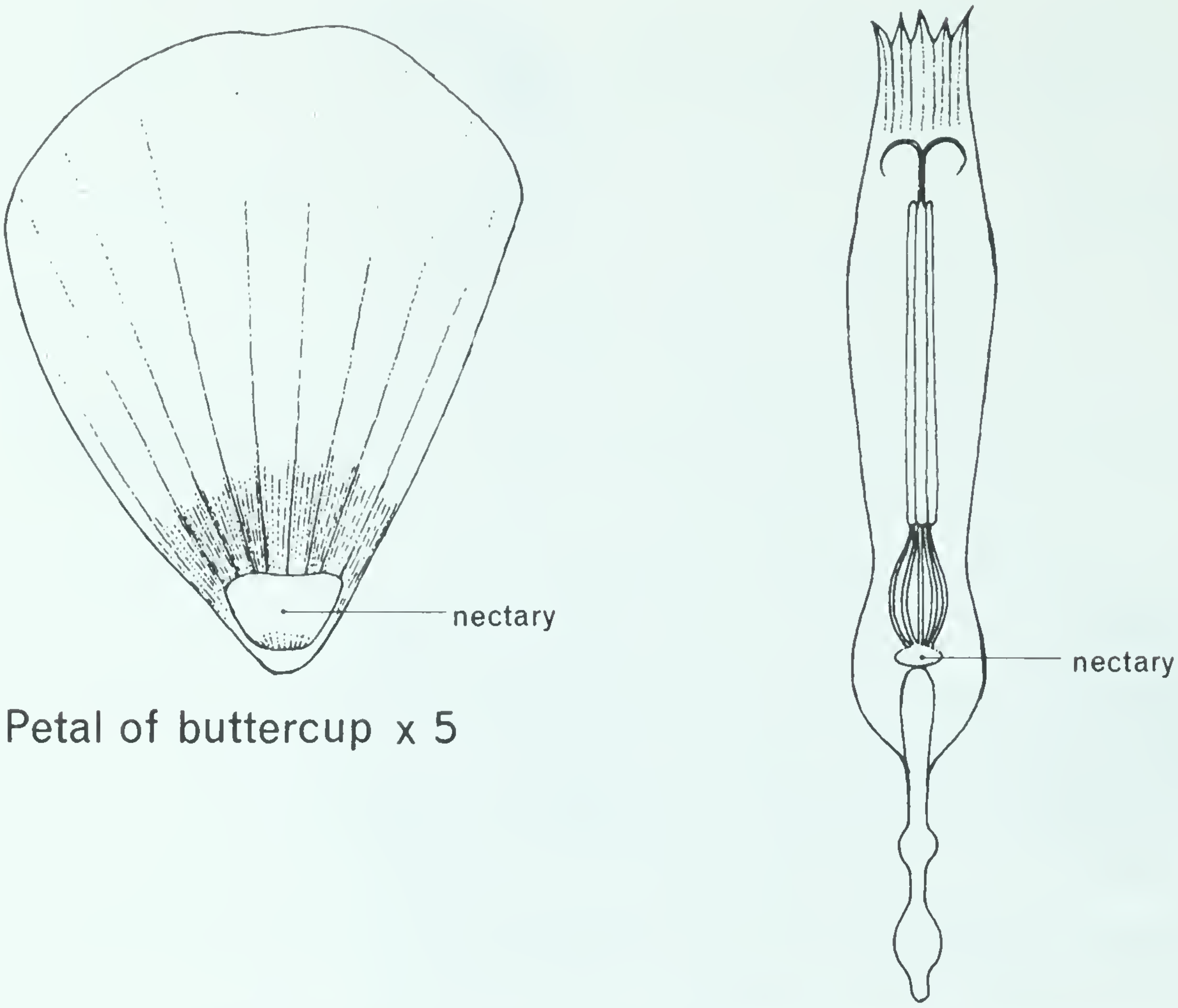


c Air-filled wings on either side of the grain help the pollen to float in the air

Figure 65
Different kinds of pollen grains. These pollen grains are all magnified about 500 times.

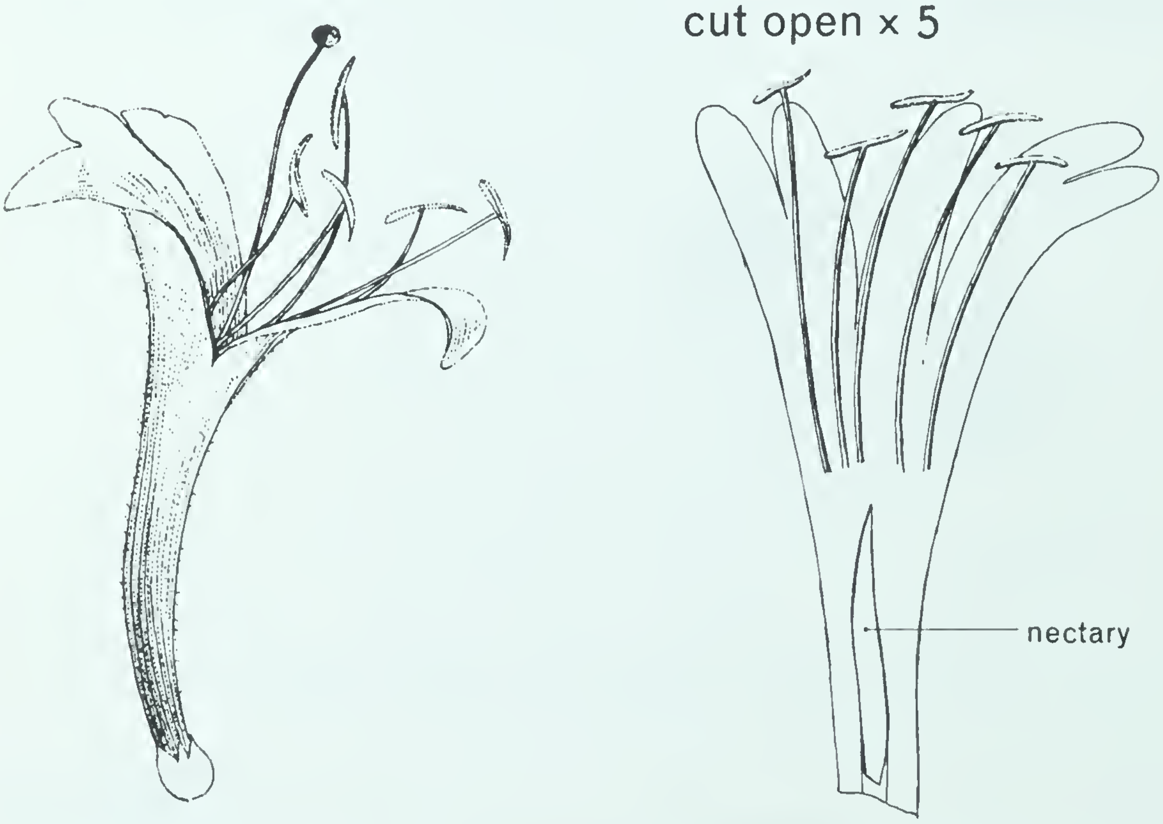
Nectar and pollen

Some insects visit flowers to collect pollen, and others to find food in the form of nectar. This is a sugary fluid made by the flower and stored in nectaries. Did you detect a familiar taste when you tasted the contents of a nectary (section 8.11)? Some flowers have coloured stripes and long rows of hairs on the petals which assist visiting insects in finding the nectaries.



a. Petal of buttercup x 5

b. Single floret of a dandelion cut open x 5



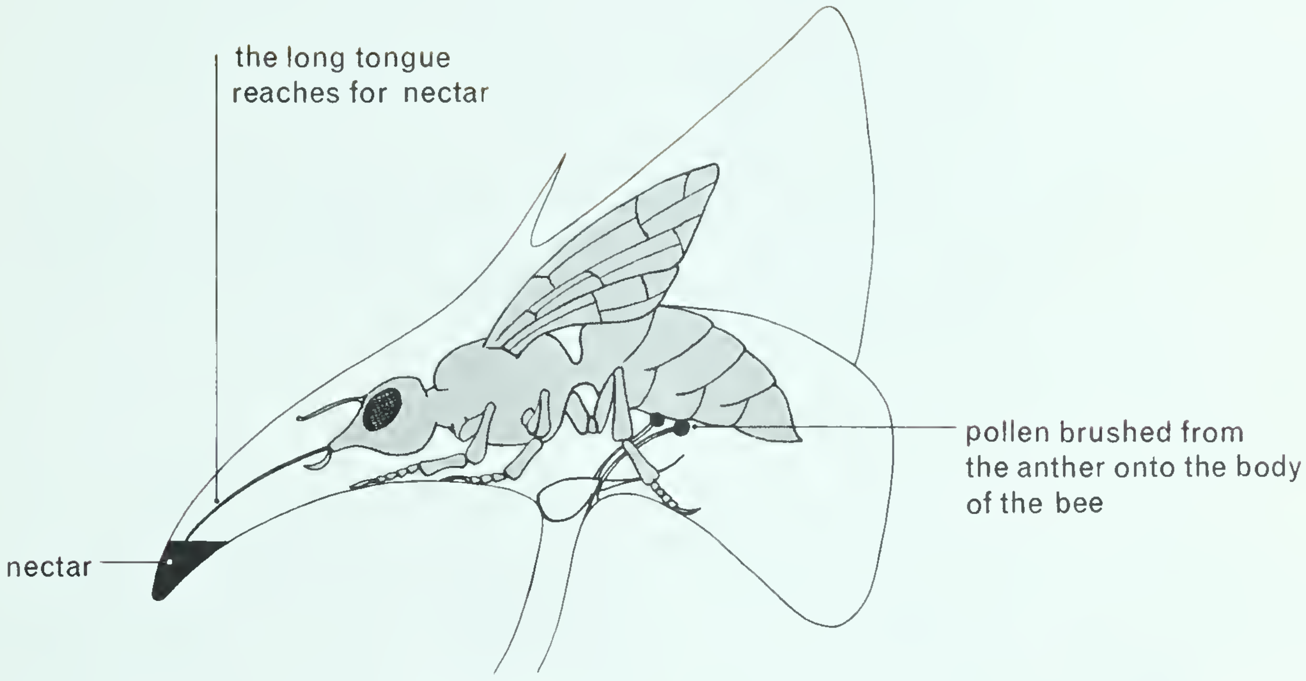
c. Honeysuckle flower x 2

d. Honeysuckle flower cut open x 2

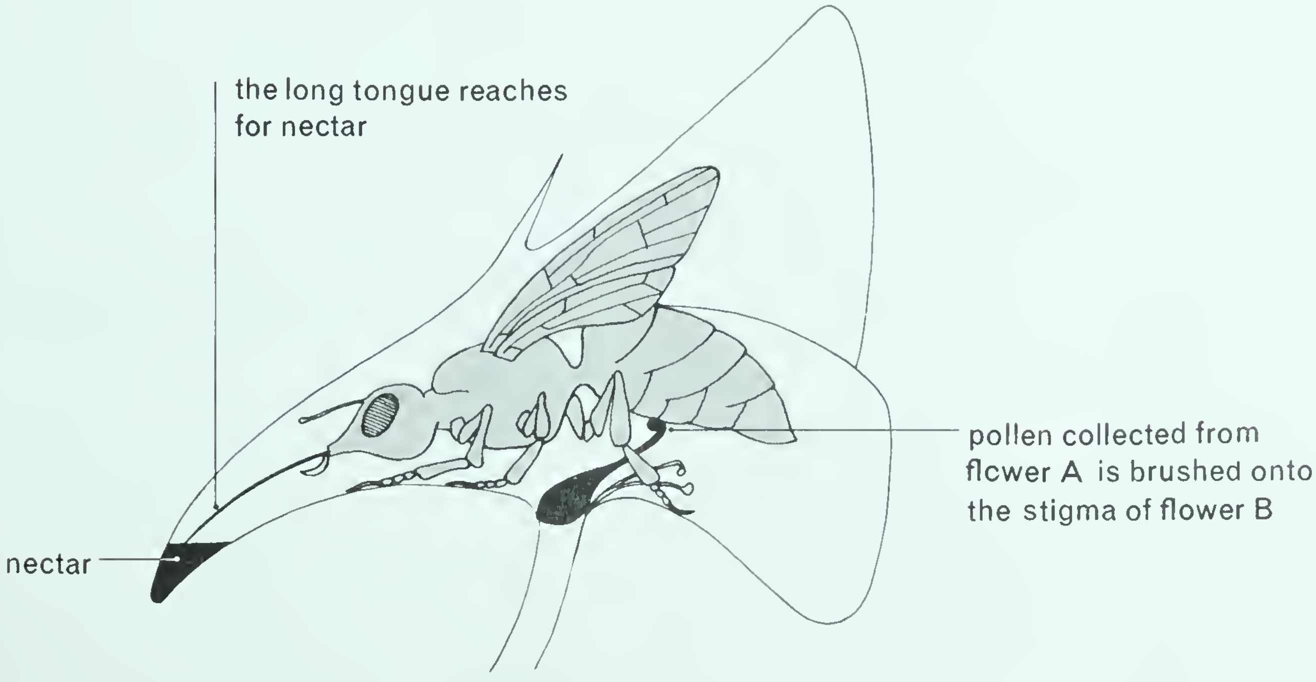
Figure 66
The position of the nectaries of some flowers.

In the flower you were looking at in section 8.11 there was a nectary at the base of each of the two outer stamens. You might try to find the nectaries in some other flowers (see figure 66).

1. Take a petal off a buttercup and look at the base of the petal with a hand lens. Can you see the little flap behind which is the nectary?
2. Pull one flower from the head of a honeysuckle or from a columbine. Bite off the end of the petal tube and taste the nectar.


the long tongue reaches for nectar
pollen brushed from the anther onto the body of the bee
nectar

Flower A


the long tongue reaches for nectar
pollen collected from flcwer A is brushed onto the stigma of flower B
nectar

Flower B

In the buttercup and dandelion the nectaries are easy for insects to reach because the flowers are shallow, so that quite small flies and beetles can get in by crawling over the flower. But in the honeysuckle or columbine the nectar lies at the bottom of a long tube so that only insects with long tongues can reach it.

Some flowers with nectaries have strong scents as well as attractive colours. The flowers of the lime (*Tilia europea*), for instance, smell strongly in the early morning while others, such as the night-scented stock and honeysuckle, are scented more strongly in the evening. Some flowers, such as tulips and lupins, may be brightly coloured and yet have no scent. Such flowers have no nectaries.

Colour, scent, and guide lines all play a part in attracting insects. This raises the more general question as to why it seems to be important for flowers to be attractive to insects and what, if anything, the plant gains from them.

If you shake a tulip or lily flower the pollen falls off the anthers in clumps and probably sticks on the petals. This is because the pollen grains are sticky. The pollen of many flowers visited by insects is rough or covered with spines to help it to stick to the body of the insect (see figures 65 and 70).

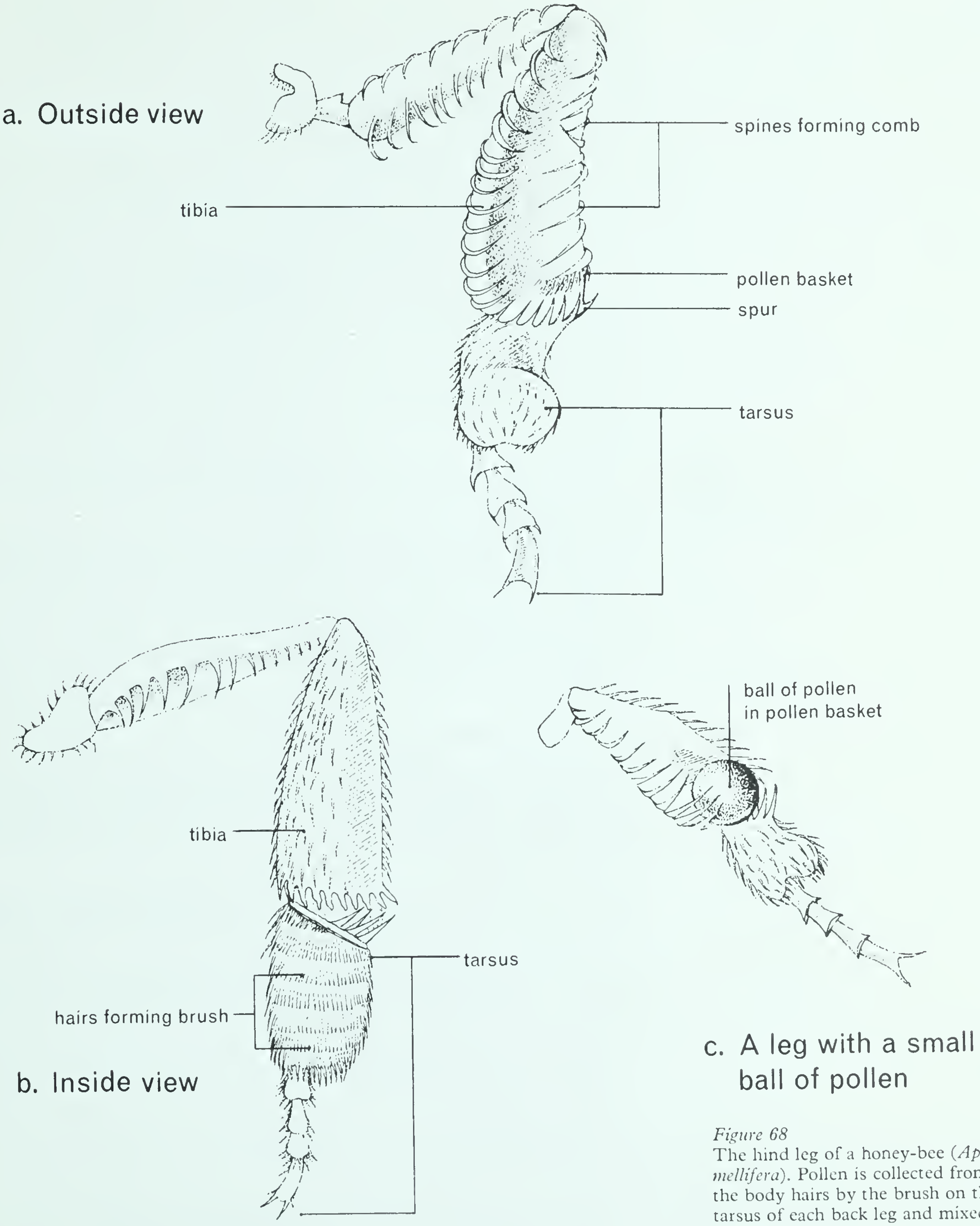
8.16 Watching insects visiting flowers

Next time you are in the garden, try watching a group of flowers for a few minutes. Before long you will probably see a honey-bee or some other kind of insect on one of the flowers. What is it doing? If the flower is like a nasturtium or a columbine in having a long spur, the insect may disappear right inside the flower and if you look carefully when it comes out again you will probably see that it is covered with pollen. Next it visits another flower and in pushing down inside the flower some of the pollen is rubbed off on its body.

Figure 67*a* is a diagram of a flower cut lengthwise and showing a bee collecting nectar from the nectary. As it does so pollen from the anthers of the stamens is brushed onto its body. In visiting another flower of the same kind the bee rubs the pollen onto the stigma of this flower. In this way the insect has transferred pollen from one flower (see figure 67*b*) onto the stigma of another. This process is called *pollination.*

Every now and then the bee uses its back legs to brush the pollen off the hairs on its body and collect the pollen in the pollen baskets on each of the back legs. Figure 68 shows how the bee does this.

You may be able to watch bees and other insects at work visiting lupins, delphiniums, and other kinds of flowers. Probably you can collect information by careful observation and try to complete the table below which gives a few of the flowers you might select. You could add other kinds which you may have noticed are visited by insects.



a. Outside view

b. Inside view

c. A leg with a small ball of pollen

Figure 68
The hind leg of a honey-bee (*Apis mellifera*). Pollen is collected from the body hairs by the brush on the tarsus of each back leg and mixed with a little nectar to make it sticky. It is then combed out with the comb of the opposite back leg and pressed into the pollen basket by means of the spur.

Kind of flower	*Flower shallow or deep*	*Colour of flower*	*Scent*	*Guide lines*	*Kind of insect visiting*
Nasturtium	Deep	Red	Yes	Yes	Bee
Dandelion	Shallow	Yellow	Slight	No	Fly
Lupin	?	?	?	?	?
Poppy	?	?	?	?	?
Honeysuckle	?	?	?	?	?

Table 1.

Try answering these questions after you have made your own observations about insects and flowers.

a. Do flowers with nectaries produce nectar all the time? How could you find out whether this is so or not?
b. When you saw a bee on one kind of flower, did it next visit a flower of the same or a different kind?
c. What kind of insects visit flowers which are open in the evening?

8.17 Pollination by wind

It is clear that insects play a very important part in transferring pollen from one flower to the stigma of another. But there are also many kinds of flowers which do not rely on insects to pollinate them but which use the wind to carry pollen.

Most grasses are pollinated by wind. By examining a grass flower you should be able to find out something about the special characteristics of wind-pollinated flowers.

Look at the flowering spike of a grass and, using a hand lens when necessary, try to answer the following questions:

1. Is the grass flower a conspicuous colour?
2. Do the stamens dangle loosely from the flowers on the spike?
3. When you shake the whole stem, does the pollen fall easily out of the flower?
4. Find the stigmas inside one of the flowers. Are they small and unbranched, or large and feathery?

Figure 69 shows a single flower of the false oat grass (*Arrhenatherum elatius*) with the stamens and stigmas.

If you have ever carried a twig of hazel catkins into the house in springtime you will remember the thick dust of yellow pollen that settles on the furniture. On a windy day clouds of pollen can be

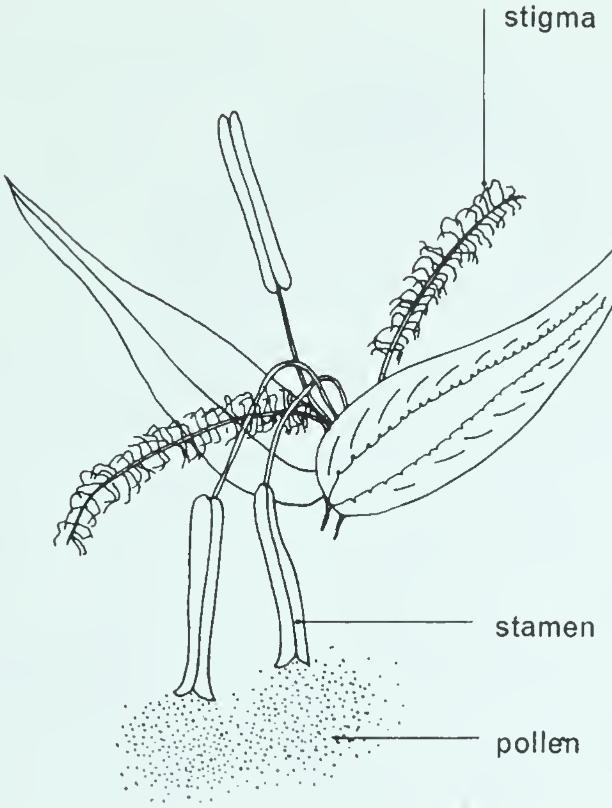


Figure 69
Single flower of false oat grass (*Arrhenatherum elatius*).

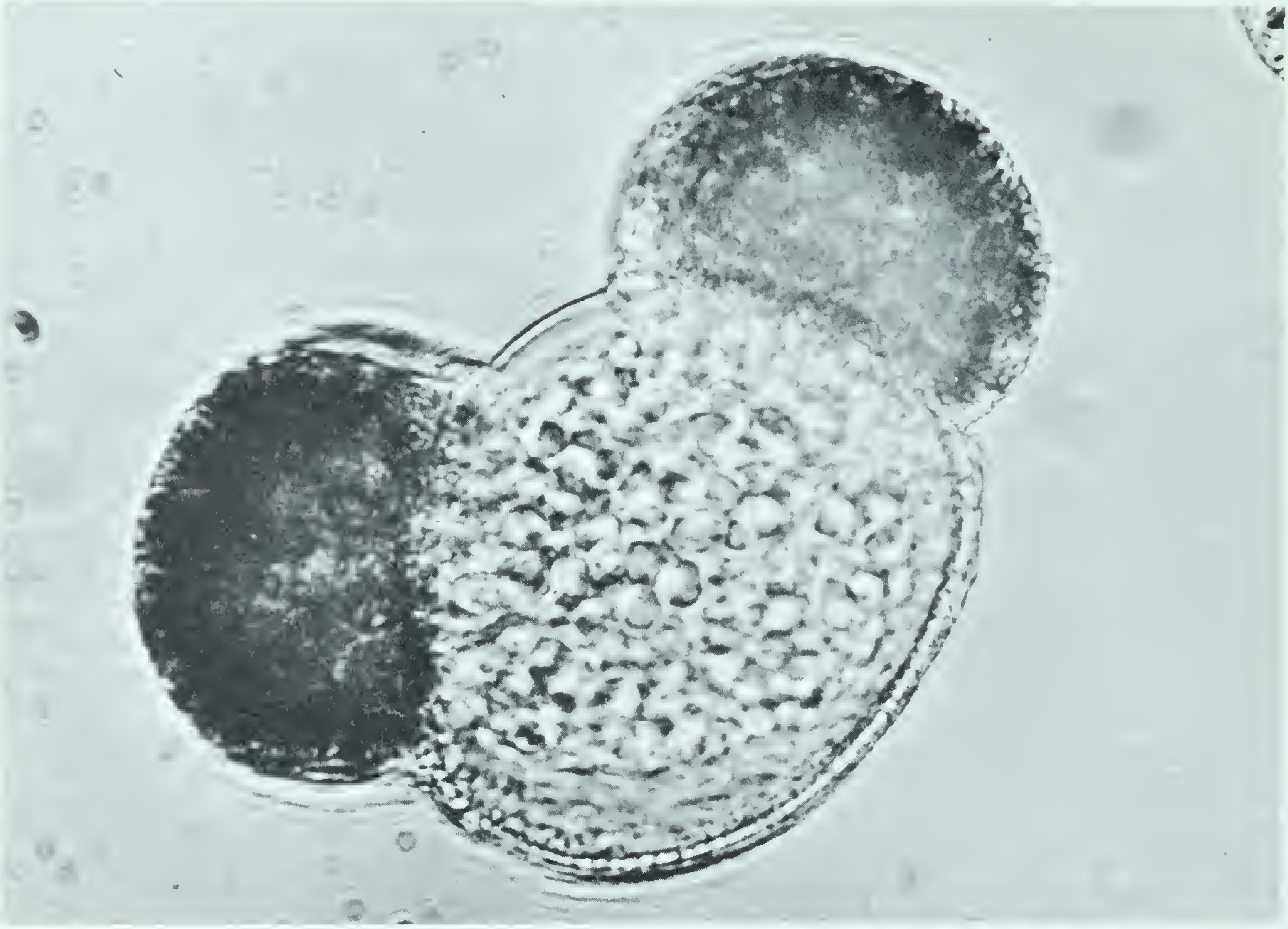
seen as hazel catkins are blown about. The pollen grains are small and are produced in enormous numbers; they are light because of the air-filled wings on either side of each grain like those of the pine (see figures 65 and 70). Most wind-pollinated plants have pollen of this kind, which is able to float in the wind. The female flowers have large stigmas which increase the chance of pollen grains landing on them (see figure 71).

We can say, then, that in wind-pollinated plants the flowers do not need to be large and colourful, but they must produce plenty of pollen on stamens which can swing about in the wind. The stigmas must be large in order to stand a good chance of catching the flying pollen grains.

8.18 Growing pollen grains

We have seen that insects of many kinds carry pollen from one flower to another and that wind can also do the same.

The pollen itself is often sticky; so is the surface of the stigma. Once the pollen has fallen onto the stigma it tends to stay there. But what happens next? How do the pollen grains, which contain the male reproductive cells, reach the ovary in which are the ovules containing the female reproductive cells? In some plants the style is very long. If you have examined a honeysuckle flower, for instance, you will have seen that the style can be an inch or more in length. Thus the pollen on the stigma will somehow have to travel this distance to reach the ovules at the other end (see figure 66). In order to do this a tube grows out of the pollen grain. This is called the pollen tube and we say that the pollen has *germinated*. Figure 72 is a diagram of a pollen grain just starting to germinate. Figure 73 is a photomicrograph of pollen grains starting to



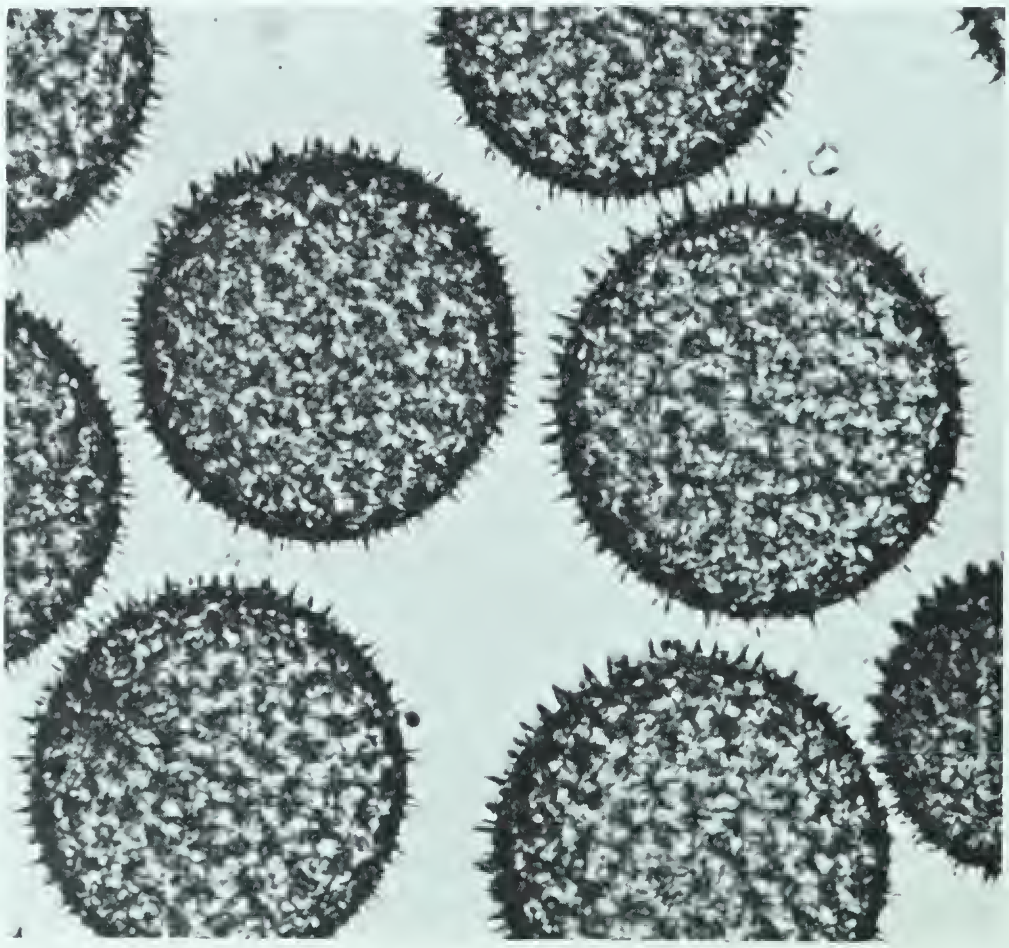


Figure 70
Photomicrographs of different kinds of pollen, under high power.
a. Pollen grain of the black pine (*Pinus nigra*) × 2000. The two air sacs make it light and easily blown about by the wind.
Photo, R. H. Noailles.
b. Pollen of the common mallow (*Malva sylvestris*) × 200. The pollen grains are covered with spines which help the grains to cling to the hairs on the body of an insect visiting the flower.
Photo, R. H. Noailles.

germinate on projections on the surface of the stigma. The grains and pollen tubes are not inside the projections but are attached to their surface.

We know very little about what causes pollen to germinate, but the stigmas contain sugar, which is essential for the germination of pollen in many plants. Some kinds of pollen prefer a strong sugar solution, some a weak sugar solution, and others no sugar at all. There is a chance for you to find out what strength of sugar solution different kinds of pollen require for germination or whether some kinds of pollen will germinate without any sugar solution at all.

1. The class must be divided into four groups.
2. Each group is provided with the *same* three kinds of flowers but with either distilled water or with a different strength of sugar solution.
3. The different groups should try germinating their pollen in the following solutions:

Group I	Distilled water
Group II	5 per cent sugar solution
Group III	10 per cent sugar solution
Group IV	15 per cent sugar solution

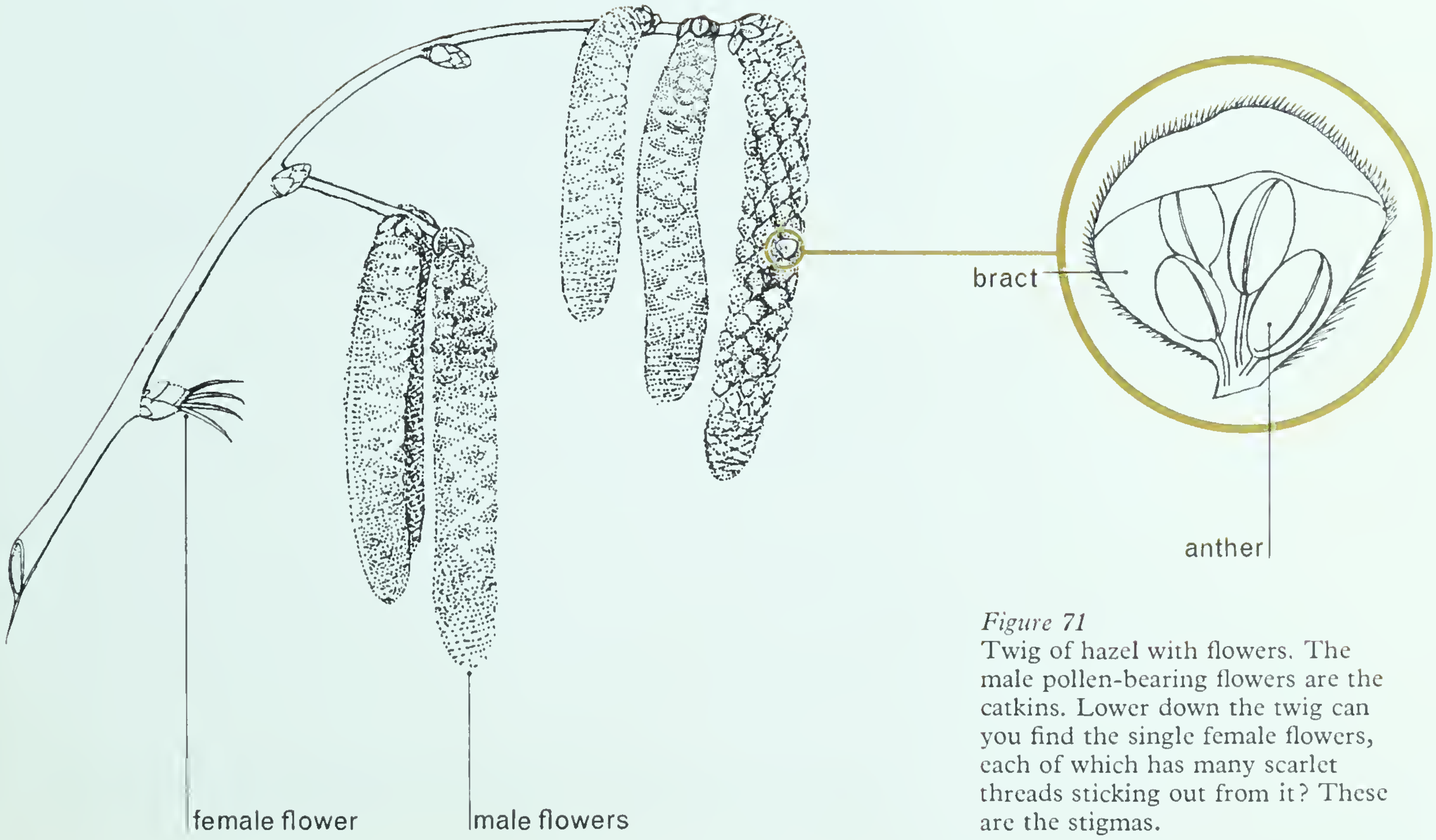
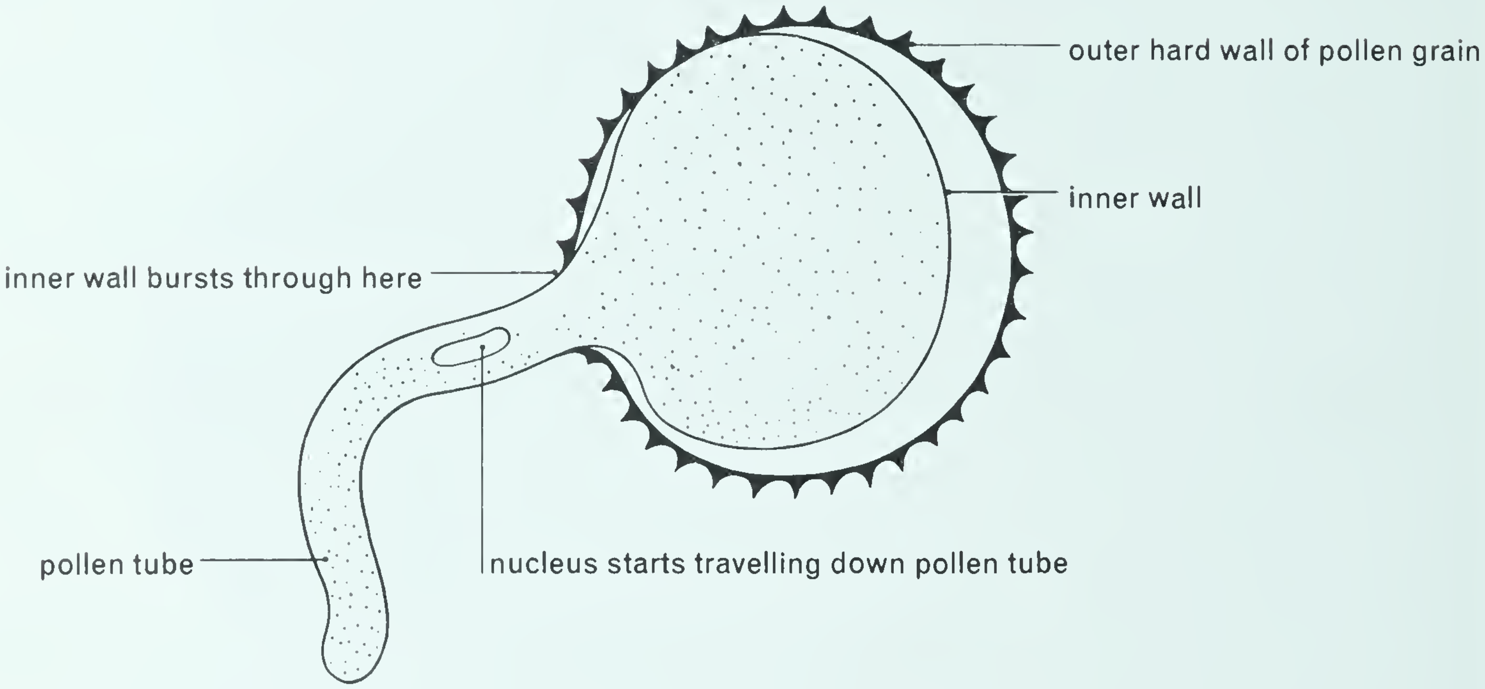


Figure 71
Twig of hazel with flowers. The male pollen-bearing flowers are the catkins. Lower down the twig can you find the single female flowers, each of which has many scarlet threads sticking out from it? These are the stigmas.

Figure 72
A pollen grain starting to germinate. The pollen tube grows down the style and eventually into the ovary of the flower. The nucleus of the grain travels down the pollen tube.


outer hard wall of pollen grain
inner wall
inner wall bursts through here
pollen tube
nucleus starts travelling down pollen tube

In your notebooks prepare a table, like the one below, ready to record the results of your own group and those of the others.

Pollen	Tubing shape	*Results* Estimate of number of pollen grains that have germinated 'most', 'many', 'few', or 'none'			
		Group I Distilled water	*Group II* 5 per cent sugar solution	*Group III* 10 per cent sugar solution	*Group IV* 15 per cent sugar solution
Narcissus	△				
Tulip	□				
Bluebell	○				

Table 2.

Each group is provided with a Petri dish, filter paper, a solution of sugar or distilled water, and three flowers.

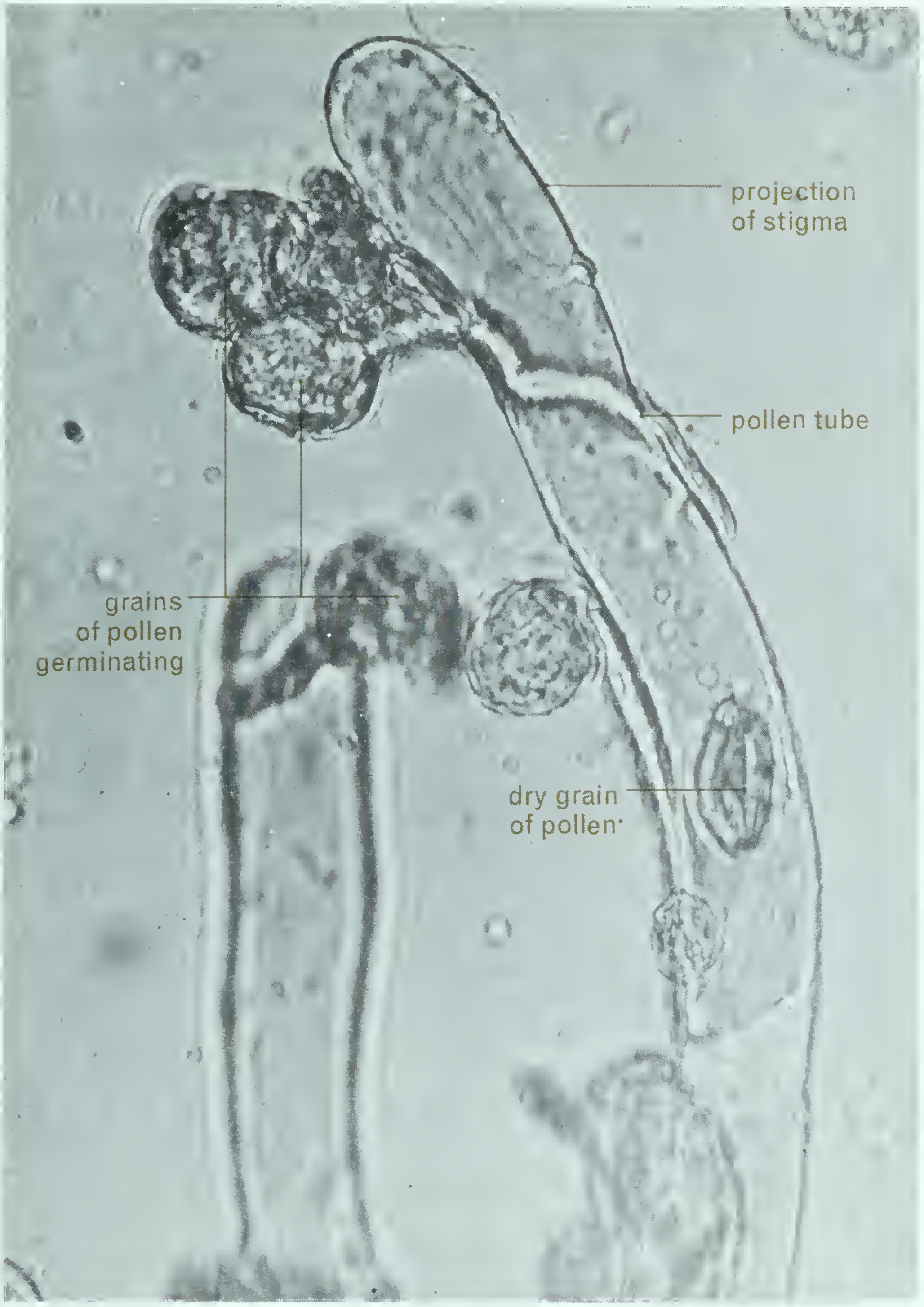
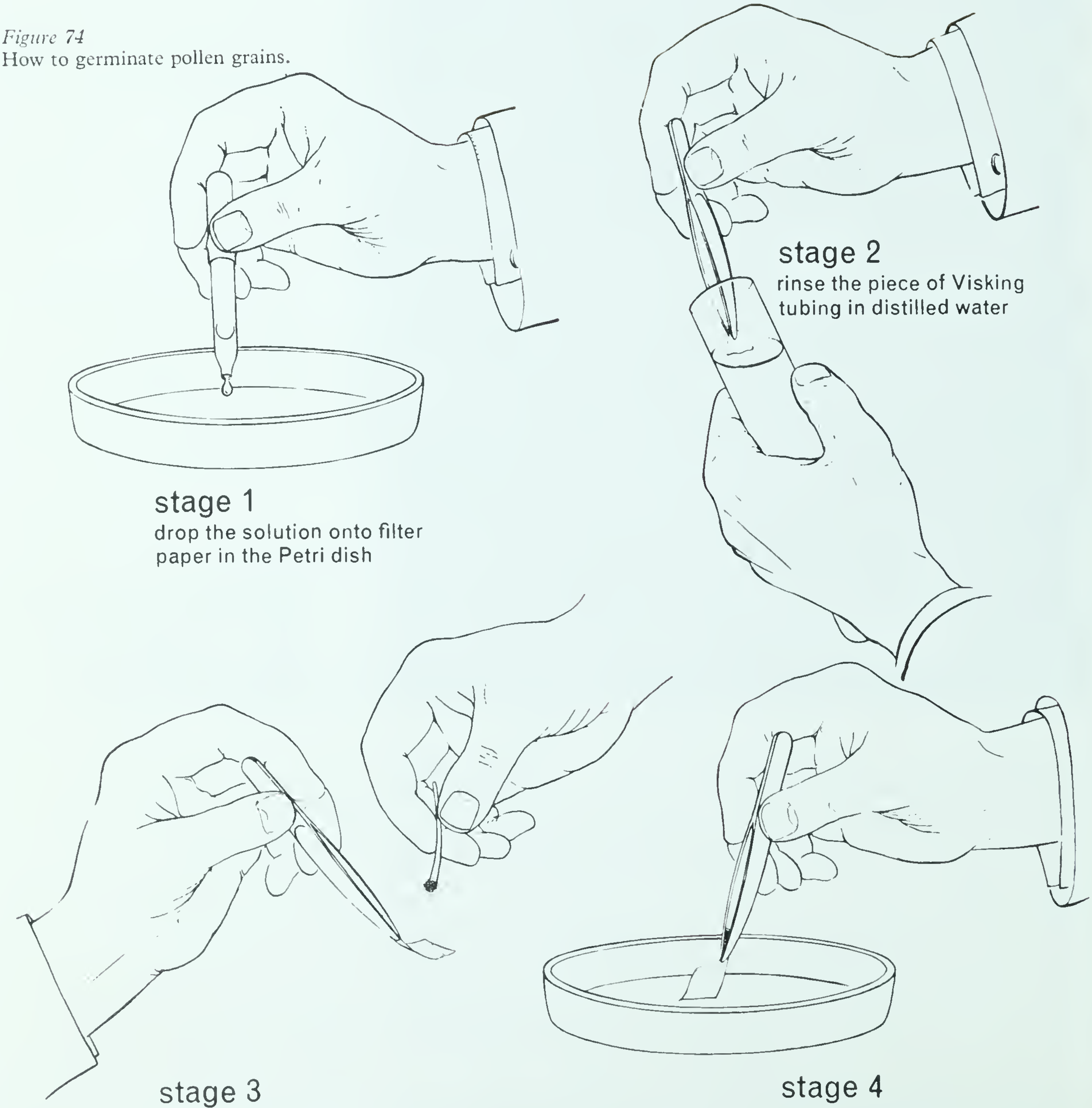


Figure 73
Photomicrograph of pollen grains germinating on projections of a stigma. Each of the many grains settling on the stigma of a flower can germinate and grow pollen tubes. *Photo, R. H. Noailles.*

1. Place filter paper in the bottom of the Petri dish and, using the pipette, drop enough solution onto the filter paper to make it completely damp all over (see figure 74, stage 1).
2. Cut some Visking tubing of single thickness into three different shaped small pieces about 2 cm across (square, circle, and triangle) as in figure 74.
3. Using forceps, rinse these pieces of tubing in a test-tube of distilled water (see figure 74, stage 2).
4. Remove the triangular shaped piece from the test-tube with the forceps and, taking out a ripe stamen from a narcissus flower, dust the pollen onto the triangle, noting in your table the name of the flower and the shape of the tubing (see figure 74, stage 3).
5. With forceps place this shape on the filter paper in the Petri dish (see figure 74, stage 4).

6. Repeat (4) and (5) for each of the other two kinds of flower, using the other shapes of tubing.
7. Put the lid on the Petri dish. With a Chinagraph pencil mark the number of your group on the lid, and leave the dish in a warm place.
8. After a day or so carefully remove each piece of tubing in turn from the Petri dish with forceps. Place it in a drop of distilled water on a microscope slide. Cover with a cover-slip.
9. Focus under low power of the microscope. Are any of the

Figure 74
How to germinate pollen grains.



stage 1
drop the solution onto filter paper in the Petri dish

stage 2
rinse the piece of Visking tubing in distilled water

stage 3
dust the piece of Visking tubing with pollen

stage 4
place the piece of Visking tubing onto the filter paper

pollen grains starting to germinate and looking like the one shown in figure 70?

10. Record your results in the table (but first read the notes below) *before* you make the next slide.

Recording and comparing your results

It would be impossible to count all the pollen grains you shook onto the pieces of Visking tubing and it may be difficult to count the number of grains that have germinated. Thus you must invent a simple system of recording in the columns of your table the numbers of grains that have germinated something like this: most, many, few, or none.

By comparing your results with those obtained by the other groups, you can tell whether pollen from each of the three flowers germinated best in distilled water or in one of the sugar solutions of different strengths.

8.19 Pollen grains, ovules, and seeds

In the experiment you have just finished you were imitating what happens in the flower itself after the pollen has fallen on the stigma. The pollen tube grows down the style to reach the ovary at the bottom. Figure 75 shows a number of pollen grains which have settled on the stigma of a flower. Some have started to grow pollen tubes which push their way between the cells of the style.

Look at the prepared microscope slide. Can you see the pollen grains on the surface of the stigma. And can you see that some of them have pollen tubes which are growing down between the cells of the style?

You cannot see what happens next because it would need a much more powerful microscope, and more time than we can spare. So we must finish the story by looking at figure 76. This

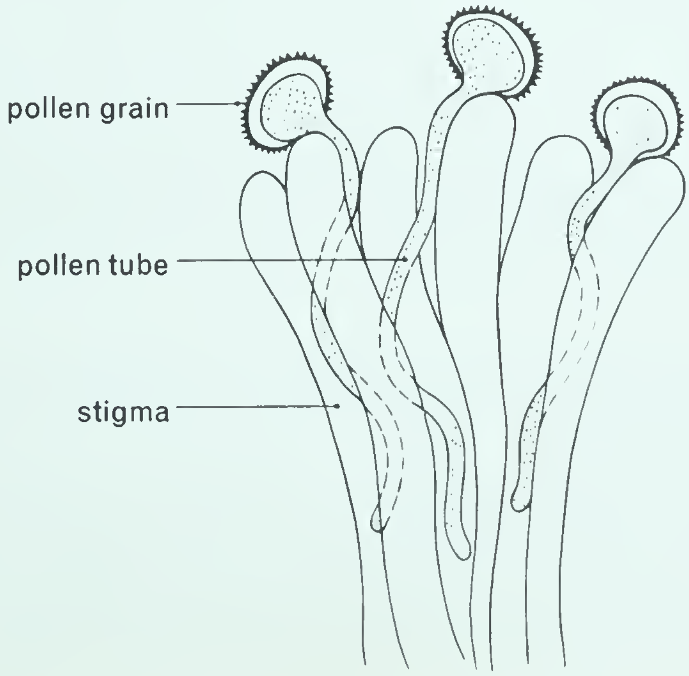


Figure 75
Pollen grains germinating on the stigma of a flower. The pollen tubes have started to grow down between the finger-like processes of the stigma.

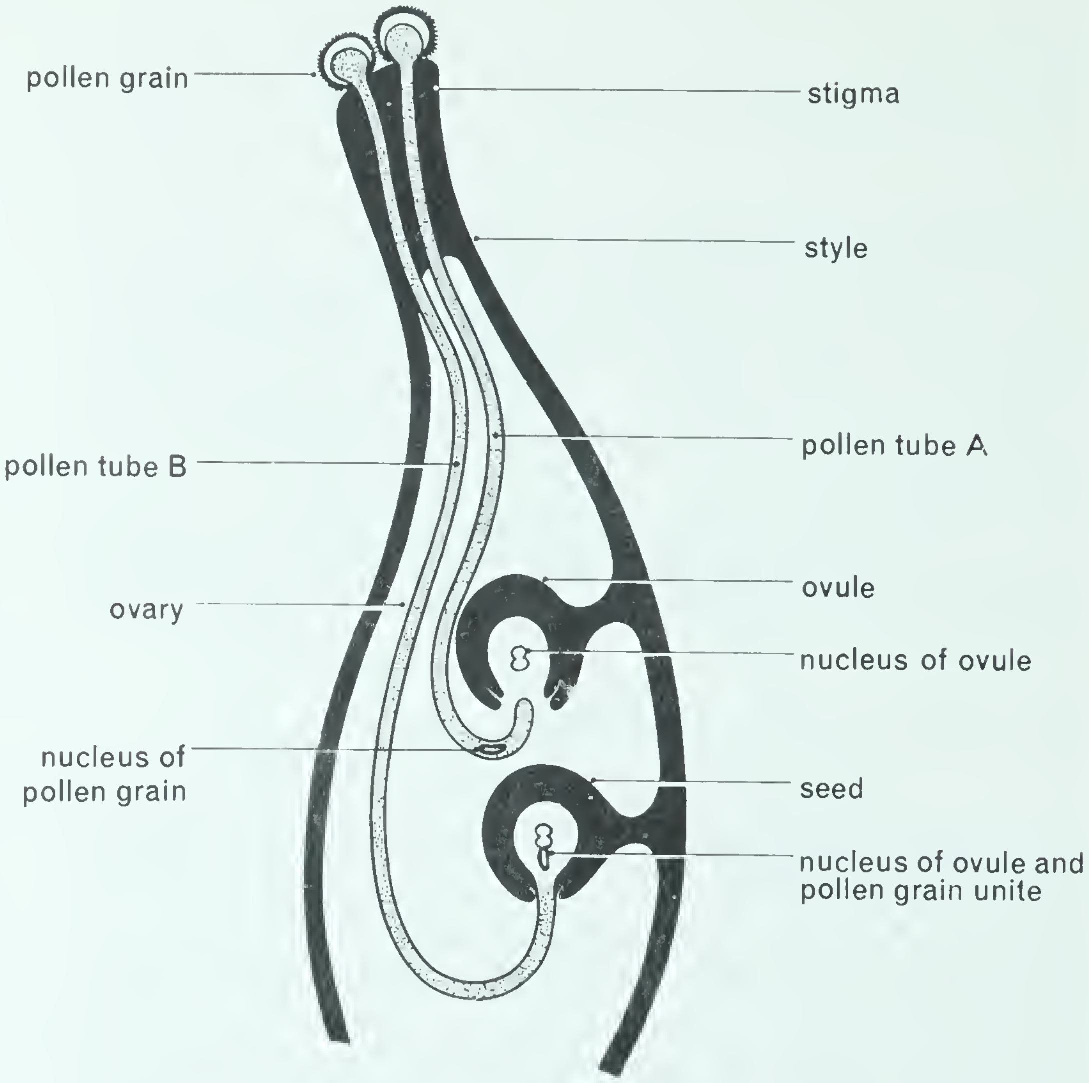


Figure 76
The top part of a very young pea pod cut lengthwise. The pollen grains on the stigma have grown long pollen tubes down the style and into the ovary. Tube A has just reached an ovule while the nucleus of the tube B is uniting with the nucleus of the ovule and fertilizing it.

shows the top portion of a very young pod of peas, so young that it is still inside the pea flower. The pollen tubes A and B have grown right down the style and into the ovary. The pollen tube A has pushed into an ovule and the pollen grain nucleus is travelling down the pollen tube. Pollen tube B has not only grown into the ovule but the tip of the pollen tube has dissolved. The nucleus of the pollen grain which has travelled down the pollen tube is joining with the nucleus of the ovule.

You will remember that in animals the egg cell was fertilized by a sperm. In other words, the nucleus of the egg and the nucleus of the sperm joined together. The same thing takes place in plants when an ovule is fertilized. The nucleus of the pollen grain joins the nucleus of the ovule. This *fertilized ovule* is called a *seed* and starts to grow.

8.2 What happens if the pollen is not allowed to reach the stigma

We can investigate quite easily what happens to ovules if they are kept out of contact with pollen. We have only to cut out the stamens from the flower before the pollen is ripe, and then cover the whole flower so that pollen from elsewhere cannot reach the stigma.

The most suitable kind of flower to use would be one in which, like radish, there are only a few stamens. Radishes are usually dug up and eaten when the plants are quite small, but if you allow them to go on growing they will soon develop flower buds that open out into flowers, starting with the one nearest the top of the plant.

1. Remove all the fully opened flowers on a radish plant labelled A. (Why must they all be removed?)
2. Open a bud and with a sharp-pointed pair of scissors, cut out the stamens. There are six of them.
3. Do this with three or four other buds on the same plant. If there are more than this number, remove the rest. (Why must this be done?)
4. Push a garden cane into the ground beside the radish plant A and tie the plant to it so that it has some support.
5. Enclose the whole of the flower head on which the buds are growing in a bag made of muslin, and tie the open end of the bag tightly round the stem of the plant so that no insects can enter.
6. Mark another radish plant (labelled B) on which there are flowers and buds, by tying a piece of coloured wool round the stem.
7. After two or three weeks take the muslin bag off A and carefully examine each flower from which you have cut out the stamens. Have the ovaries swollen at all?
8. Look at plant B. The petals of the flowers will now have fallen off. Has the ovary in any of these flowers swollen? Compare the state of the ovaries in A and B. Leave the coloured wool on B to mark it for examination later on.

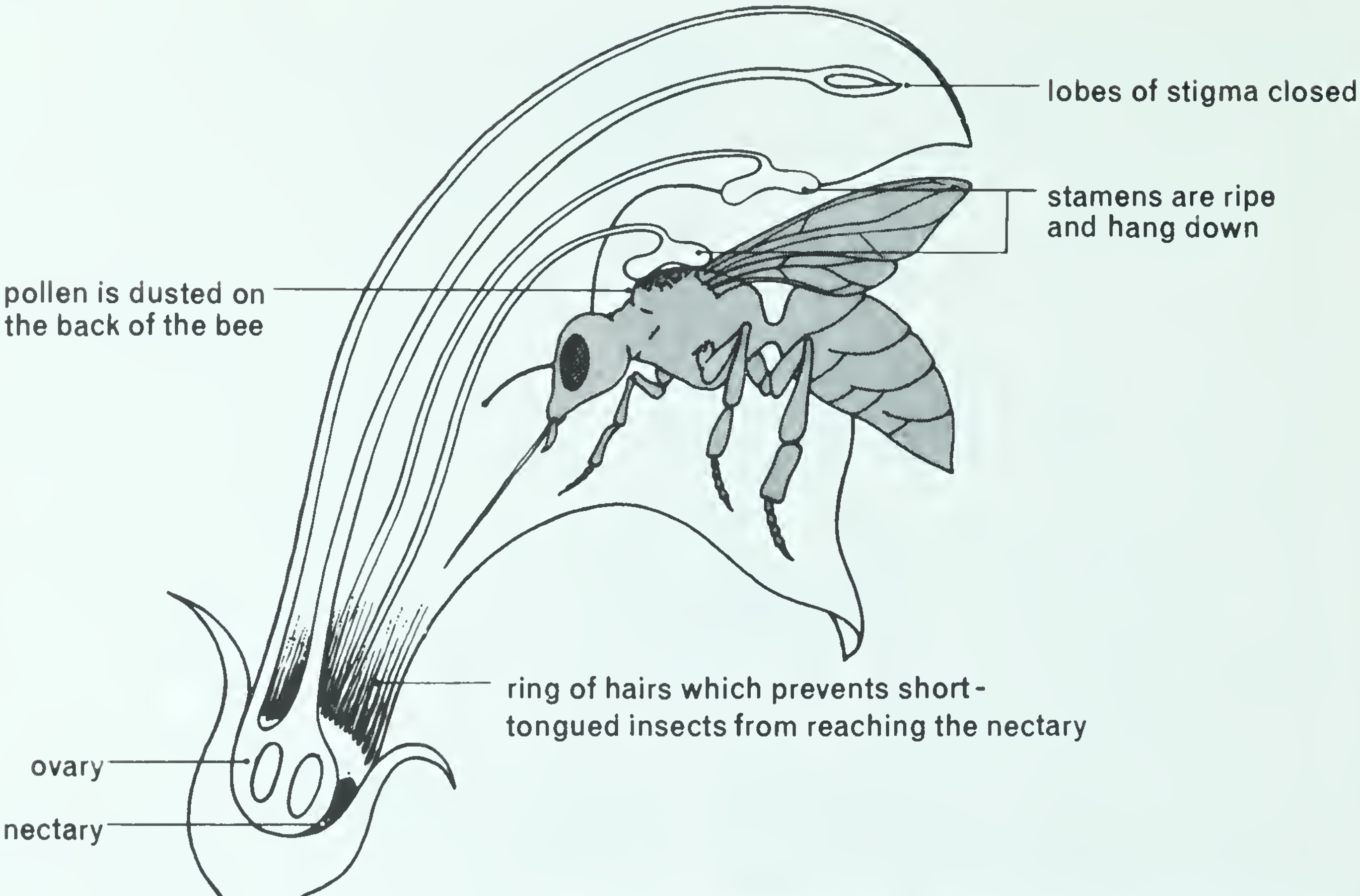
Can you answer these questions?

a. Why must you enclose the flowers from which you have cut out the stamens in a muslin bag?
b. Why must the flowers still be in bud when you do this?
c. Why do you mark another flower of the same kind but not enclose it in a muslin bag?

Once the ovules have been fertilized with pollen they become seeds. This you have already learnt in section 8.19. The seeds start to grow, and the wall of the ovary must therefore grow bigger also. The whole structure – seeds and ovary wall – is then called the *fruit*. Look again at figure 67. This is the young fruit of the wallflower.

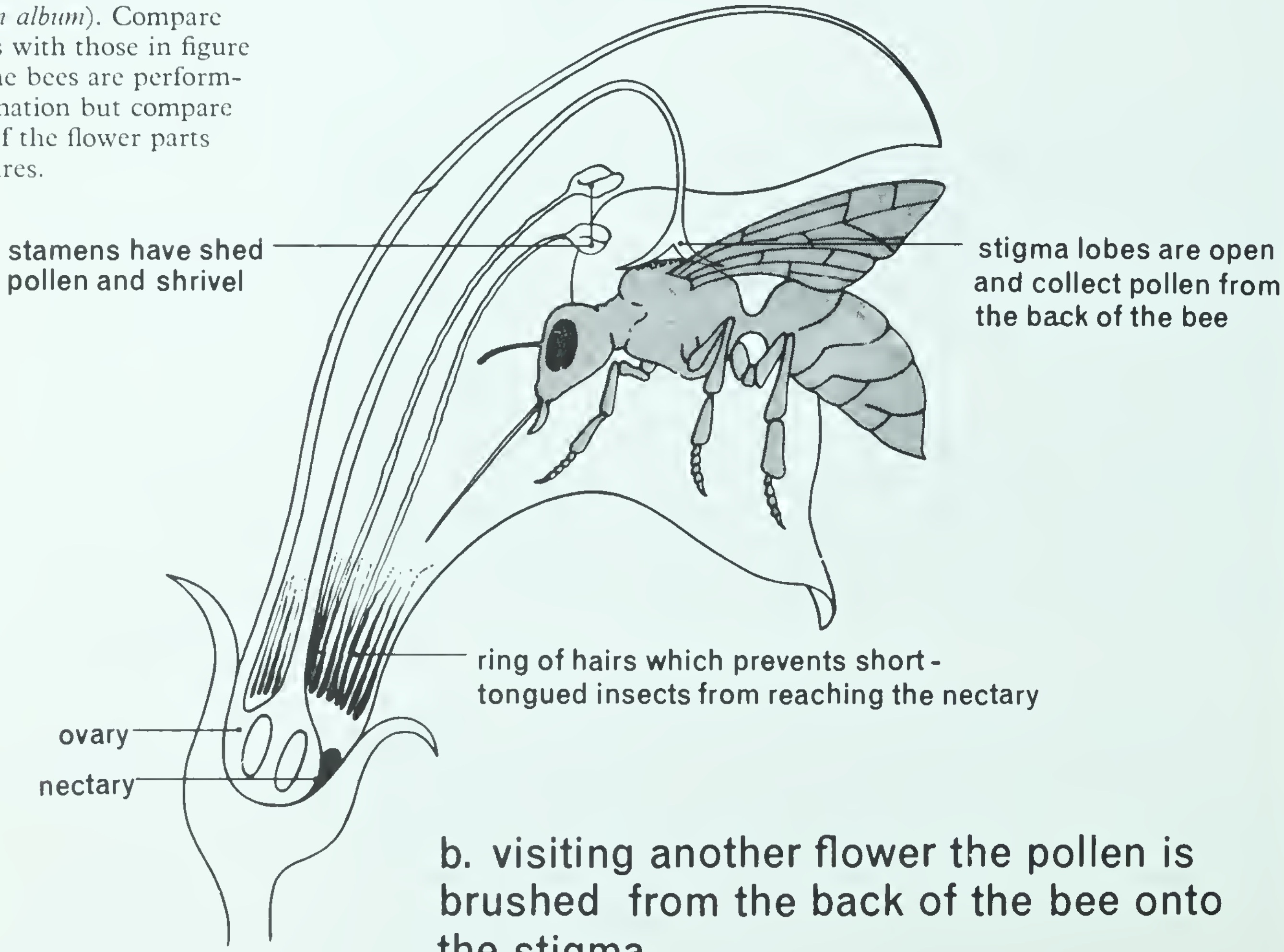
8.21 Pollen from another flower or from the same flower?

So far we have found by experiments that insects and wind can carry pollen from one flower to another. Look once more at figure 67. The bee has carried pollen from flower A to flower B. When this happens we say that the flower has been *cross-pollinated*. But very often pollen can fall on the stigma of the *same* flower to fertilize the ovules. In such cases we say that the flower has been *self-pollinated*.


lobes of stigma closed
stamens are ripe and hang down
pollen is dusted on the back of the bee
ring of hairs which prevents short-tongued insects from reaching the nectary
ovary
nectary

a. pollen is dusted on the back of the bee

Figure 77
Cross-pollination in white dead-nettle (*Lamium album*). Compare these drawings with those in figure 67. In both, the bees are performing cross-pollination but compare the positions of the flower parts in the two figures.


stamens have shed pollen and shrivel
stigma lobes are open and collect pollen from the back of the bee
ring of hairs which prevents short-tongued insects from reaching the nectary
ovary
nectary

b. visiting another flower the pollen is brushed from the back of the bee onto the stigma.

You could experiment to see whether self-pollination is really possible. A tulip is a good flower for this purpose.

1. Enclose a tulip flower in a muslin bag as you did with the radish plant, but do not cut out the stamens. You may have a small stick in the ground and tie the tulip to it for support.
2. Take the muslin bag off, after a week or so. What has happened to the petals? What has happened to the ovary? How can you tell if the female part of the flower has been pollinated?

On the whole it is better for a flower to be cross-pollinated than self-pollinated because it will result in a more vigorous new plant, but there are many kinds of flowers which nevertheless are always self-pollinated. The ordinary garden pea and the sweet pea are examples of self-pollination.

8.22 Some ways in which flowers ensure cross-pollination

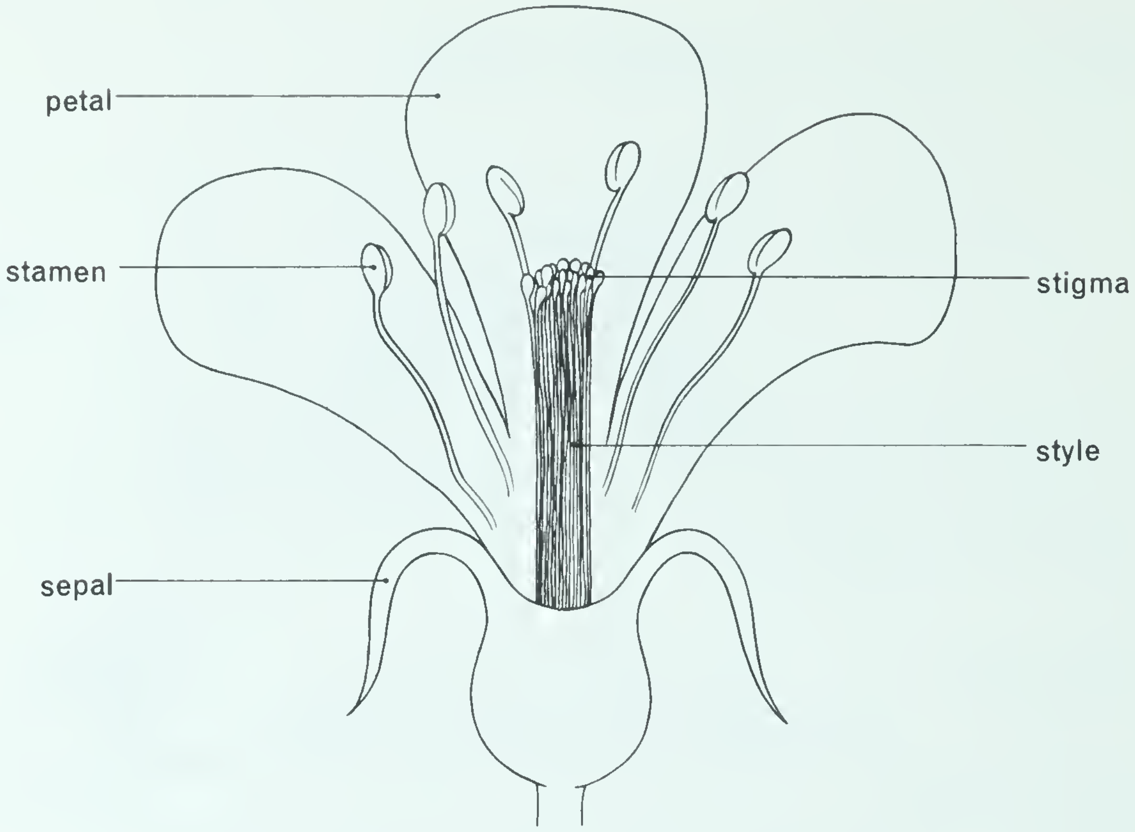
Some flowers are specially designed to make sure that they are cross-pollinated.

White deadnettle (*Lamium album*) is a common flower in May which you can often find in hedgerows and on waste ground. The diagrams in figure 77*a* and *b* show what happens when a bumble bee visits a white deadnettle flower. The bee lands on the lower lip of the flower, which forms a convenient platform, and presses into the flower to find the nectar in the nectary at the base of the ovary. As it does so the long style is jerked out of the hood and touches the back of the bee on which there is pollen which it has collected from another white deadnettle flower (see figure 77*a*). Withdrawing from the flower the back of the bee next rubs against the anthers (see figure 77*b*), collecting pollen as it does so. This it carries to the next flower that it visits. In this way cross-pollination is achieved.

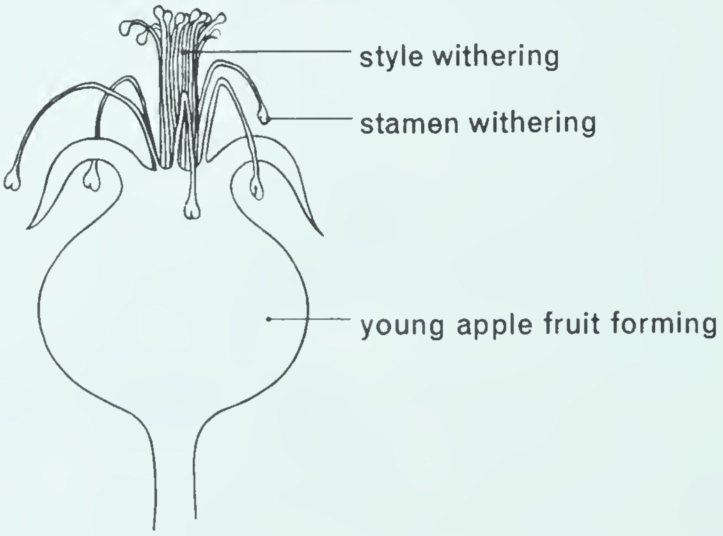
Many other flowers have special devices to make sure of cross-pollination. By keeping careful observation in a garden or in the countryside you may be able to discover that some flowers, such as the white deadnettle, have special shapes to suit special kinds of insects which visit them. You might watch bees visiting sage flowers, for instance, and find out how the design of these flowers makes sure that they are cross-pollinated.

8.3 The fruit ripens

We have seen that after an ovule has been fertilized by a pollen grain it becomes a seed, and that as the seeds inside the ovary grow bigger the ovary itself grows bigger too. Figure 78 shows how an apple fruit B is formed from an apple flower A. An unripe green apple in May or June, is very small. The pips or seeds inside are white or pale brown because they, too, are not yet ripe. But by



a. Apple flower cut lengthwise before pollination



b. Young apple fruit after pollination. The petals have fallen, the style and stamens are withering, and the fruit begins to swell.

Figure 78
How an apple fruit is formed.

autumn apples are ripe and ready to be picked. Inside the seeds are dark brown and ripe.

In section 8.2 you were experimenting with radish flowers.

1. Look for the radish plant B which you marked in the experiment with coloured wool. Have the flowers formed fruits?
2. If so, cut open one of these fruits and find the seeds. Are they ripe?

Some plants produce fruits containing only a few seeds; others produce large numbers of seeds.

1. Open several pods of garden peas and count the number of seeds in each pod. Are there any peas inside the pods which have not developed at all? Can you give a reason for this?
2. Open a poppy fruit or the fruit of an antirrhinum. Are there few or many seeds inside? Are the seeds large or small?

You could try opening a number of different fruits in this way, some of which are ripe and others not. Probably you will notice that in fruits with only a few seeds, the seeds will be small to begin with but will grow much larger. If there are a great many seeds, each one grows by a smaller amount.

8.31 Seeds are shed

After a time the fruits of plants stop growing and often become dry and brittle. The seeds inside also become dry and are scattered when the fruit eventually bursts.

If you look at a horse chestnut tree in May, you will probably see that the groups of flowers, resembling candles, are just beginning to form small fruits. These will have grown larger by the autumn when they burst open to let a 'conker' fall to the ground. The 'conker' is really the seed and sometimes a fruit contains more than one 'conker'.

It is the same with peas. As the seeds grow, the pods become dry, and the two halves of the pod eventually split open to shed the peas inside.

8.32 Sowing ripe seeds

The seeds you buy in packets are dry and ripe. They have been collected in a previous year from their respective plants. Try sowing some seeds from packets, together with some which you have collected yourself.

1. Place pieces of broken crock over the hole in the bottom of each of three plant pots marked A, B, and C.
2. Fill each pot with damp garden soil to within $\frac{1}{2}$ inch of the top, pressing it down firmly as you do so.
3. In pot A, make 10 holes with a pencil about $\frac{1}{2}$ inch deep, as in figure 79.
4. Into each hole drop a pea, taken from a packet of pea seeds (figure 79, stage 1).
5. Cover each hole with soil (figure 79, stage 2).
6. Label the pot with the name of the seed, date, and your name, written on a garden label.
7. Enclose the whole plant pot in a Polythene bag tied at the top to retain moisture, and place it in a warm place (figure 79, stage 3).
8. Make up pots B and C in the same way, using ten lupin seeds in B (or you could use nasturtium, sweet pea, or any other kind of

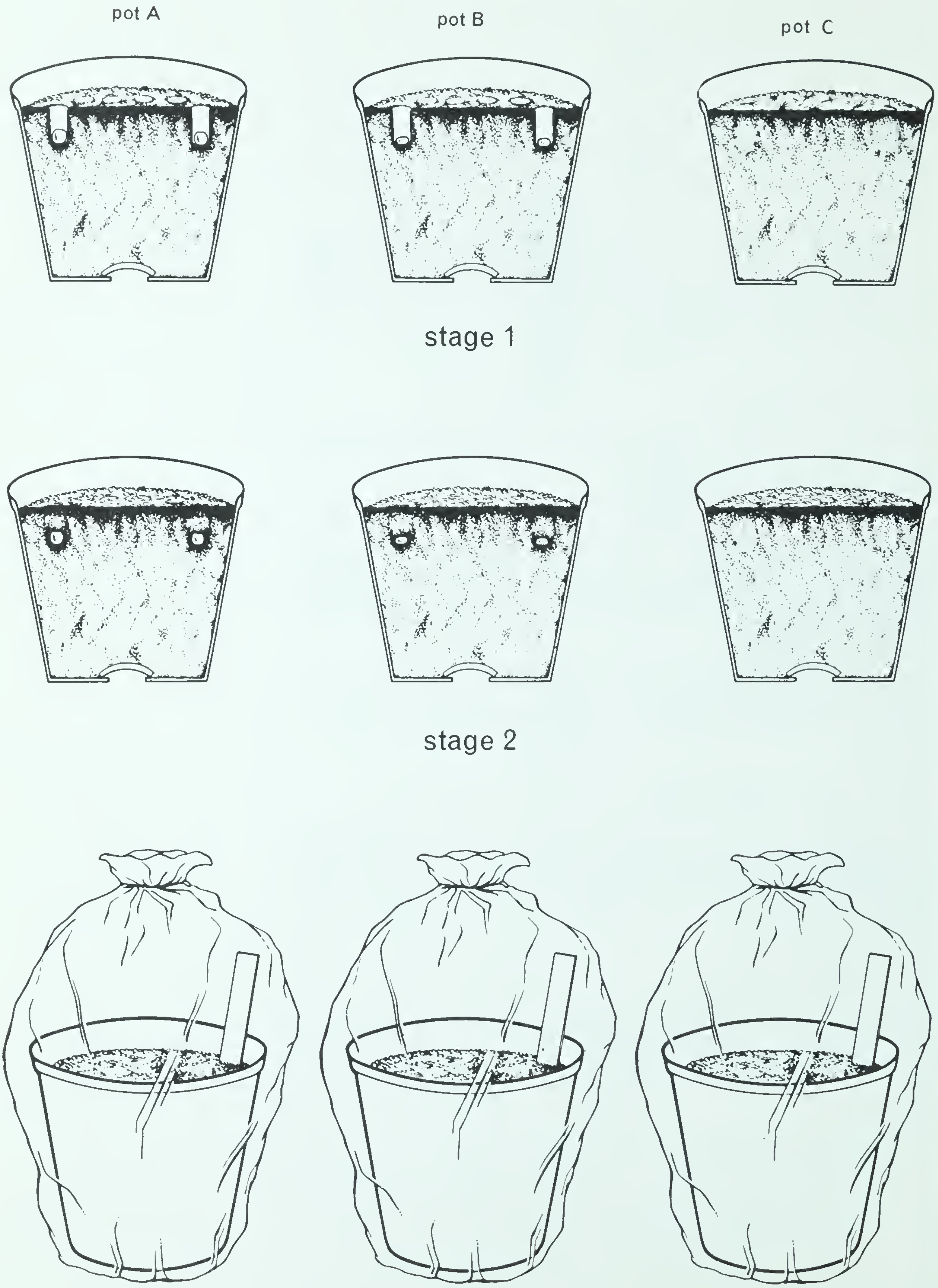


Figure 79
Sowing seeds in a plant pot.

large seed). Label as before with the name of the seed, the date, and your name.

9. On the surface of the soil in C scatter the feathery seeds of dandelion, groundsel, or the small seeds of shepherd's purse (figure 79, stage 1), and cover them with a sprinkling of soil (figure 79, stage 2). Label as before with the name of the seed sown, the date, and your name.

10. Enclose B and C in Polythene bags as you did for A and keep them in a warm place (figure 79, stage 3).

11. As soon as you see the shoots appearing, remove the Polythene bags and water the pots, keeping them warm, as before.

12. Add to the label in the pot the date on which you first saw the shoots appearing above the soil.

All three pots were kept at the same temperature. Do all the seeds take the same time to appear above the soil? If other members of the class have chosen different kinds of seeds to sow in pots B and C, you can compare the length of time each kind of seed takes to germinate.

If your experiment on growing seeds is successful you will have shown that ripe seeds germinate to give seedling plants. If you let these plants continue to grow, they may in time flower and set seed, so starting the next generation.

Summary

Pollen is produced by the male part of the flower (the stamens). The ovules are formed inside the female part (the ovary). Fertilization occurs when the nucleus contained inside a pollen grain unites with one inside the ovule. Thus the ovules and pollen grains in plants correspond to the eggs and sperms of animals.

In most animals the sexes are separate, but in most plants the male and female organs (anthers and ovaries) are found in the same flower. Some plants can be self-pollinated but most have devices that make cross-pollination more probable.

Seeds are produced from ovules which have been fertilized. They grow inside the fruit and, when ripe, they are scattered and eventually grow into seedlings. These give rise to a new generation of plants which in turn produce flowers and seeds.

Chapter 9

Growing up

9.1 What do you know about growth?

Many of the experiments and observations we have made already have shown that living things grow. Before we study other problems connected with the growth of animals and plants, let us summarize the things we have found out about growth so far. This will help us to decide what points we must investigate further.

1. Increase in size is a sign of growth. The size of an animal or plant can be measured by its height (or length), its girth, and its surface area. If any of these three dimensions is measured at intervals and found to increase this will be an indication that growth has taken place. You have measured the length of cabbage white caterpillars before they pupated. Embryo chickens were measured during the early days of their development inside eggs, and tadpoles of the African clawed toad up to metamorphosis. In all these cases an increase in length was noted which indicated growth of the animal.

2. How growth is brought about. The bodies of animals and plants are composed of cells and their bodies grow bigger because (*a*) these cells divide to make more cells, and (*b*) each new cell increases in size.

3. Environment affects growth. The *rate* at which animals and plants grow is affected by a number of things. Keeping locust hoppers at different air temperatures shows that temperature affects the rate of growth. Are there any other ways in which the environment controls growth rate – the amount of food an animal or plant takes in, for example?

9.11 Keeping mice for growth experiments

There are many animals which we might keep in order to observe how they grow up. But some of the most interesting animals to watch are mice.

We can easily breed families of young mice which we can observe as they grow. Like other mammals, mice are small and helpless when they are born. At first they obtain all their food in the form of milk sucked from the mother. They grow bigger very quickly so that when they are only about twenty days old they are able to feed themselves and leave the nest. In other words they are weaned and from that time onwards they can eat different food, such as grain, carrots, and nuts.

We could find out how they grow by weighing them, and also by measuring at intervals some part of their body such as the tail. From our results we could discover, for example, if they grow faster when they are young than when they are older, and also how long they go on growing. In other words, is there a pattern of growth?

Mice are easy to keep and to breed; provided you have suitable cages in a room which never gets very cold. They must, of course, have a regular supply of clean water and fresh food. It is best to keep to a routine when looking after mice.

1. Take out dirty bedding and litter once a week.
2. Clean the cage out and put in fresh litter once a week.
3. Change the water every day.
4. Give a fresh supply of food once a week, if pellets are used.

Bedding and litter. Dry peat, about one inch deep, in the bottom of the cage is the best since peat absorbs most of the smell and the mice will also make their nests and rear their young in it.

Food. For the experiments we are going to do, special pellet food is used which the mice cannot easily scatter.

Cages. Wooden cages with a bedroom and living room are the sort supplied by pet shops, but they are not so easy to clean out as plastic cages (see figures 80 and 81). A cage 10 × 8 × 4 inches will take about eight mice. Remember that unless you want to breed mice, the males and females should be kept separate.

Handling mice. Always pick a mouse up by its tail, holding the tail about half way along and laying it in the palm of your other hand (see figure 82). Mice soon become used to being handled, but you must be gentle and not squeeze the mouse if it struggles.

Breeding. Mice become adult and able to reproduce when they are about six to eight weeks old. The gestation period is about twenty-one days and the average size of a litter is six. If you use a plastic cage you will find that the pregnant female will make her nest underneath the metal shelter and you should be especially careful not to disturb the nest for the first few days after the babies are born. The young mice are weaned at about nineteen days old.

Sexing mice. The drawings in figure 83 show you how you can tell the difference between a male and a female. You will see that in the adult male the distance from the genital papilla to the anus is $\frac{1}{2}$ inch while in the female this distance is only $\frac{1}{4}$ inch. Only by examining several mice can you be certain because it is necessary to compare the distances in the two sexes. In the adult female the teats of the mammary glands should be visible.

You will probably need help with sexing the young mice. When they are nineteen or twenty days old they can be removed from the mother and the males should be put into one of the plastic cages

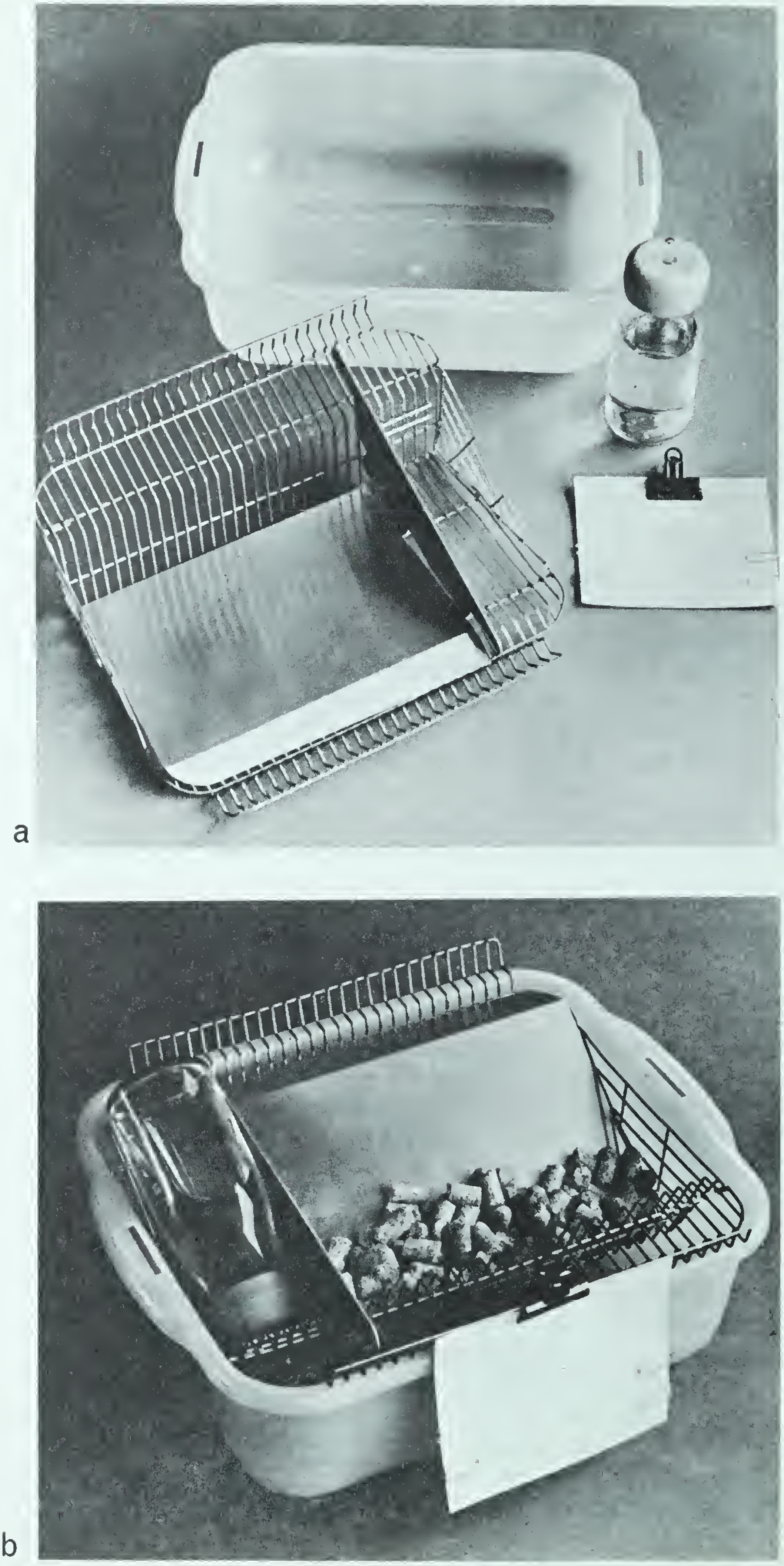


Figure 80
A cage for keeping mice (Cambridge pattern).
a. The cage showing the separate parts.
b. The cage assembled with the water bottle in position and pellet food in the food hopper. Note the record card.
Photos by Alan Gentle.

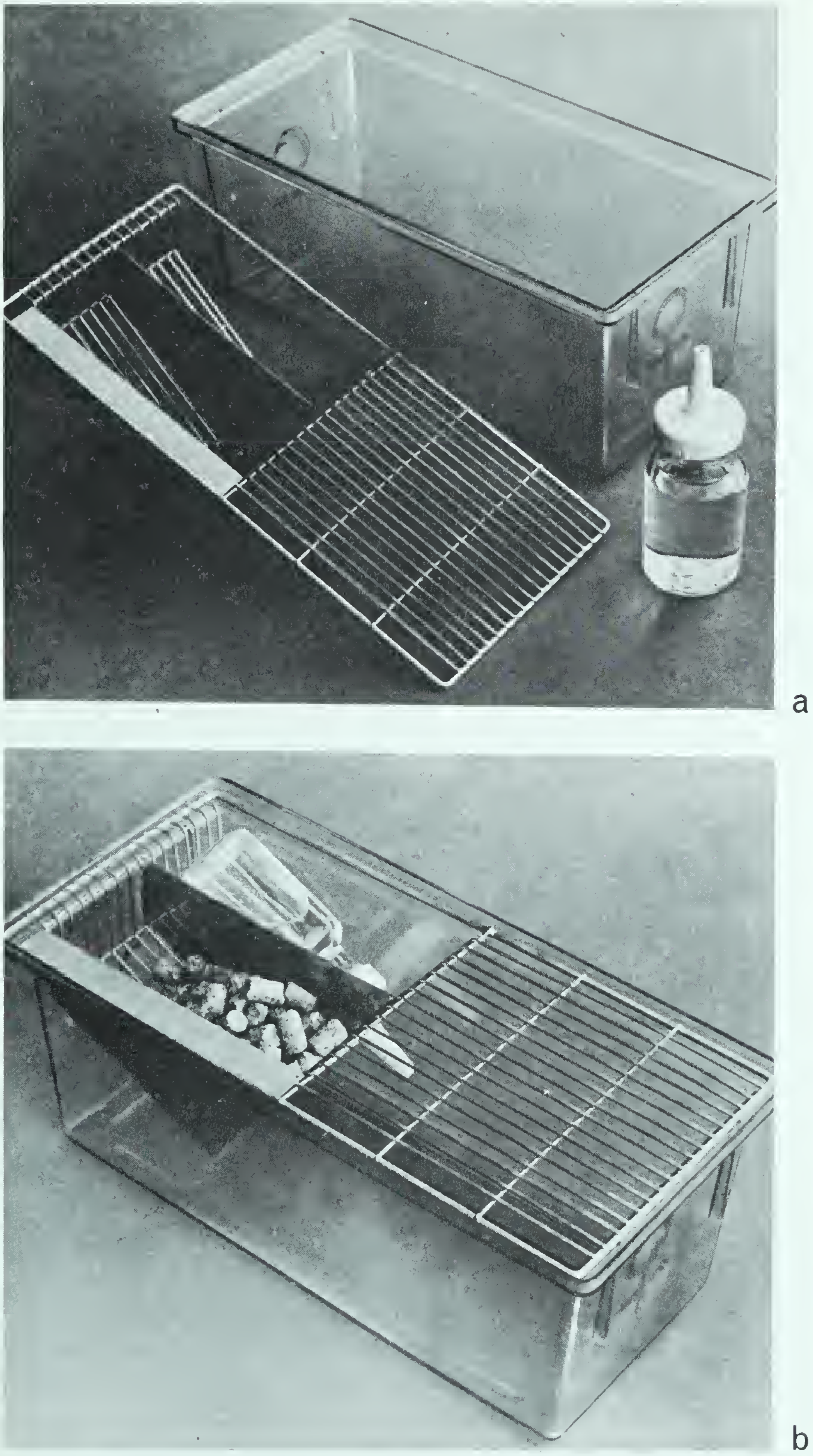


Figure 81
A different kind of mouse cage which is transparent.
a. The cage showing the separate parts.
b. The cage assembled with the water bottle in position and pellet food in the food hopper.
Photos by Alan Gentle.

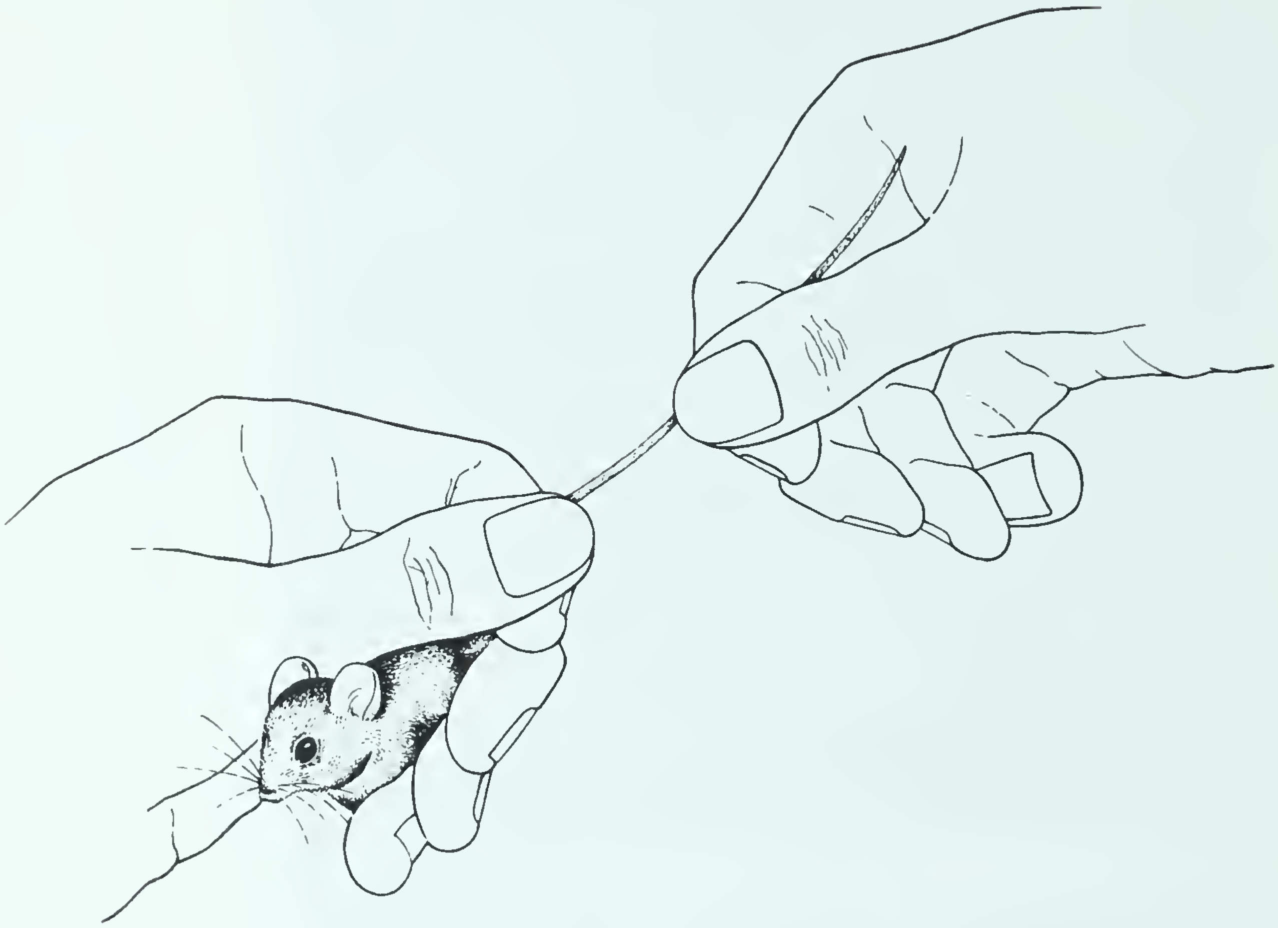


Figure 82
The right way to pick up and hold a mouse.

and the females into another plastic cage prepared ready to receive them with peat litter, water, and a weighed amount of pellet food (see section 9.12). If you have been able to raise two litters you will probably have at least five males and five females.

Keeping records

Growth is a most important characteristic of living things, but it takes place slowly. Thus measurements will have to be made over a period of time. Some of the experiments can take place together by taking two sets of measurements at the same time. It is therefore particularly important to keep careful records from which you can make your hypotheses.

9.12 Finding out about how mice grow up

We have already seen that many living things increase in height or length as they grow so that by measuring young mice once or twice a week we could find out how quickly they grow up. Measuring a live mouse would be difficult but you could measure its tail.

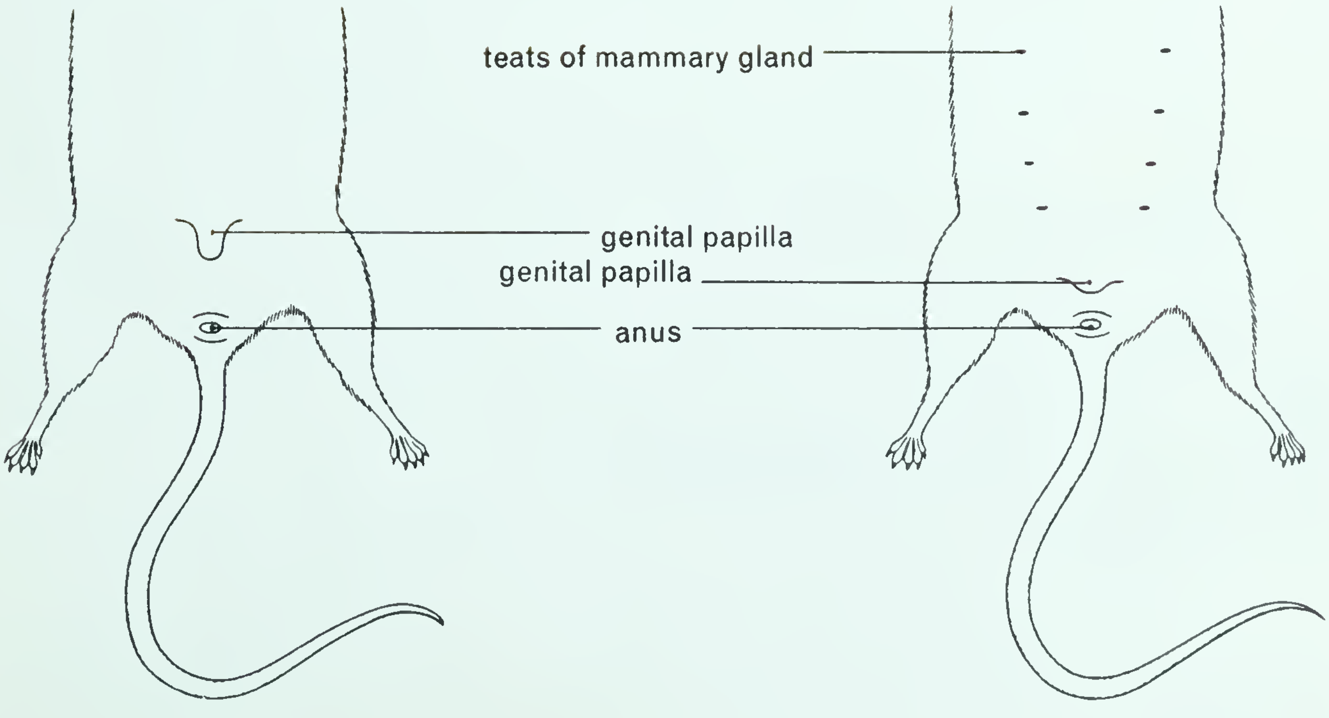
By weighing them each week we can see if they get heavier as they get older and whether they put on weight more quickly at first than they do later on. To save time you could work in groups and make both sets of measurements on the mice at the same time. You can also find out how much food they eat each week and whether they eat more food as they get older. To do this you will have to weigh out (*a*) the fresh pellet food each week, and (*b*) the amount of pellet food that is left over at the end of that week. By deducting (*b*) from (*a*) you will find out how much food they have eaten during the week.

Male and female mice may not grow at the same rate. If you want to compare the growth of the males with the growth of females, you should keep separate records. You will also have to consider whether you would get a correct idea of how mice grow if you just weigh one mouse and measure its tail. Would it not give you a more accurate result if you weighed all the males, calculating their *average* weight? In the same way you could calculate the average weight of the females and the average tail length of each sex.

Before you begin your measurements prepare a table like the one below to receive your results:

Date	Average tail length in cm		Average weight in g		Average weight in g of food eaten by 1 mouse in 1 week	
	Males	Females	Males	Females	Males	Females
16.6.66	6	6	13·5	12·5	121·5	105·6
23.6.66	?	?	?	?	?	?
30.6.66	?	?	?	?	?	?
7.7.66	?	?	?	?	?	?

Figure 83
How to sex mice.
a. Adult male.
b. Adult female.



a adult male

b adult female

Once a week for the next four weeks you will need to make your measurements and record your results in the table. Do your weighing and measuring at the same time of the day each week.

1. Place the whole cage containing the males inside a large cardboard box made into the shape of a funnel. Remove the wire lid of the cage and tip the mice gently into the bottom of the funnel. Next remove the false cardboard floor of the funnel and let the mice run into the plastic box. Before you remove the funnel from this box, slip the lid onto the box.

2. Transfer the plastic box to the weighing scales and, as quickly as you can, weigh the mice in the box. To allow for the weight of the plastic box itself, you must either weigh the box first when it is empty, or put another, to balance it exactly, on the other pan of the scales.

3. Replace the false floor of the cardboard funnel and put the plastic box inside the funnel. Remove the lid and lift out one of the mice by its tail.

4. Place the mouse inside the mouse tail measuring box (drawn in figure 84), and put your hand over the box to prevent the mouse escaping, while you hold its tail out along the scale and measure the length of the tail in centimetres.

5. Now put this mouse back in its own plastic cage and measure the tail of another.

6. When you have measured all their tails and returned the mice to the cage, you should weigh the food left in the food hopper, weigh out a fresh supply of pellets (400 g) and calculate the average weight of food eaten during the week by one mouse, recording this in your table.

7. Remember to change the water in the water bottle and check the water every day, ensuring that the tube is not blocked.

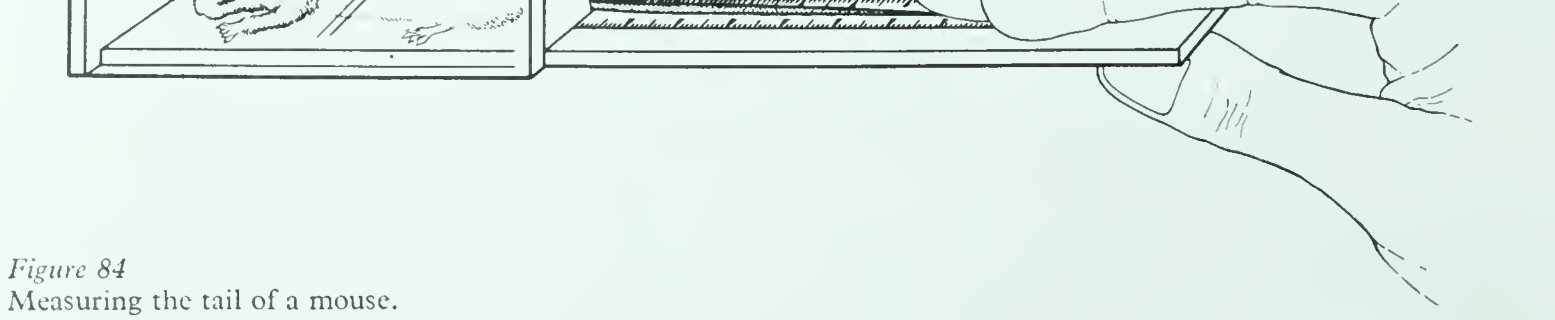


Figure 84
Measuring the tail of a mouse.

8. Repeat the whole process for the cage of female mice.

At the end of the four weeks examine your table of results. Is the amount of food eaten by the males in four weeks more than that eaten by the females? Is the average weight of the males more than that of the females? From your results would you say that there was any connection between increase in weight and increase in the length of tail? Why were you asked to weigh the mice at the same time of day on each occasion?

9.13 Finding out about growth in plants

It would be difficult to show with plants as we have done with mice – that as they grow they increase in weight. This is because we cannot weigh a plant while it is still growing in the soil. But we can measure the height of a plant each week and see if it grows taller. This would be making the same kind of measurement as we made with the tails of the mice.

You are provided with ten wheat seedlings in a plant pot:

1. With a ruler measure the height of all the wheat seedlings in centimetres, from soil level to the tip of the shoot of each seedling (see figure 85).
2. Each week repeat these measurements and, just as you did with the mice, calculate their average height. Record this figure in a table like the one below:

Date	Average height of ten wheat seedlings in cm
1.6.66	3
8.6.66	?
15.6.66	?
22.6.66	?

It will be obvious enough from your results that both mice and seedlings are growing up. But is there a *pattern* of growth – are the seedlings and the mice respectively growing the same amounts each week? Can we compare the rate of growth in the male and female mice? To do this we must use our results to construct growth curves.

9.14 Making growth curves

By making graphs of your results and joining the points on your graphs you will probably find that they form a curve. You have made graphs before but, this time, by using different symbols, you can plot the increase in weight of the male and female mice on one

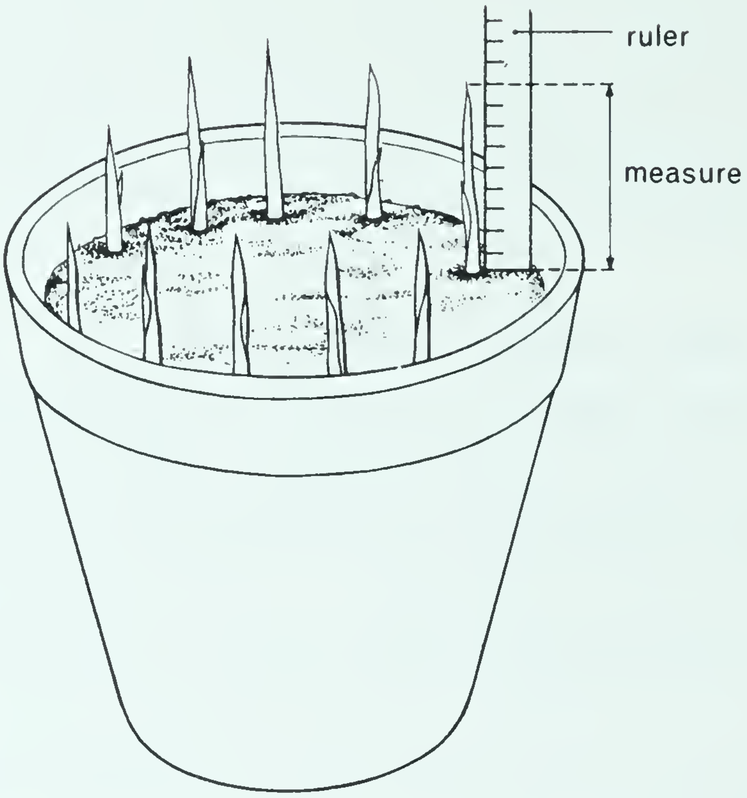


Figure 85
Measuring the height of wheat seedlings.

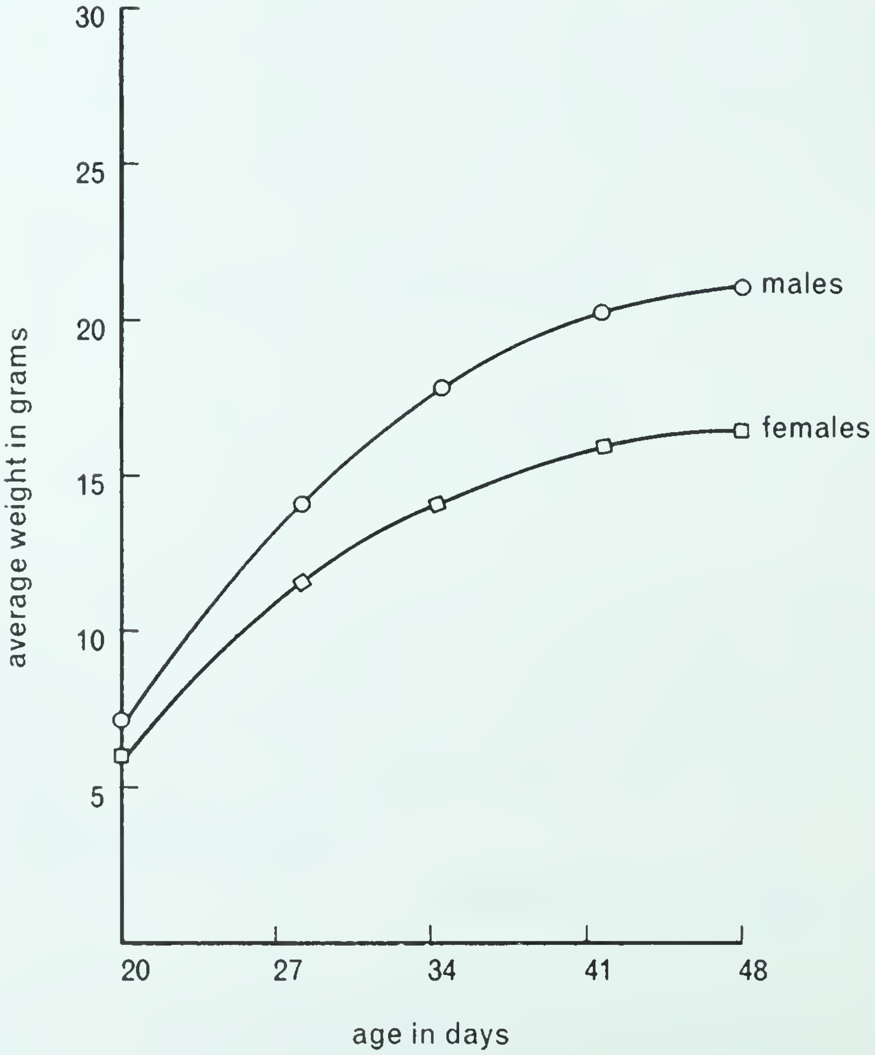


Figure 86
Graph to show the increase in weight of male and female mice.

graph. It will then be easier for you to compare your results than it would have been from columns of figures in a table.

1. Along the bottom of a page of graph paper draw a line and divide this equally into four, marking it off into the four weeks of the experiment.
2. From the left hand end of this line draw a vertical line and mark this off equally representing grams.
3. From your table of results, plot the points on your graph of the average weights of the male and the female mice.
4. Join the points, using one colour for drawing the growth curve of the males, and another colour for that of the females (see figure 86).
5. Make a second graph, which may look like figure 87, of the average lengths of the tails in the male and female mice.
6. Make a third graph, which may look like figure 88, of the average height of the wheat seedlings.

When you have finished drawing the curves from your results, look at them carefully and see if you can answer these questions:

a. Did the mice (whether males or females or both) increase in weight faster at any time during the four weeks than during the rest of the time?

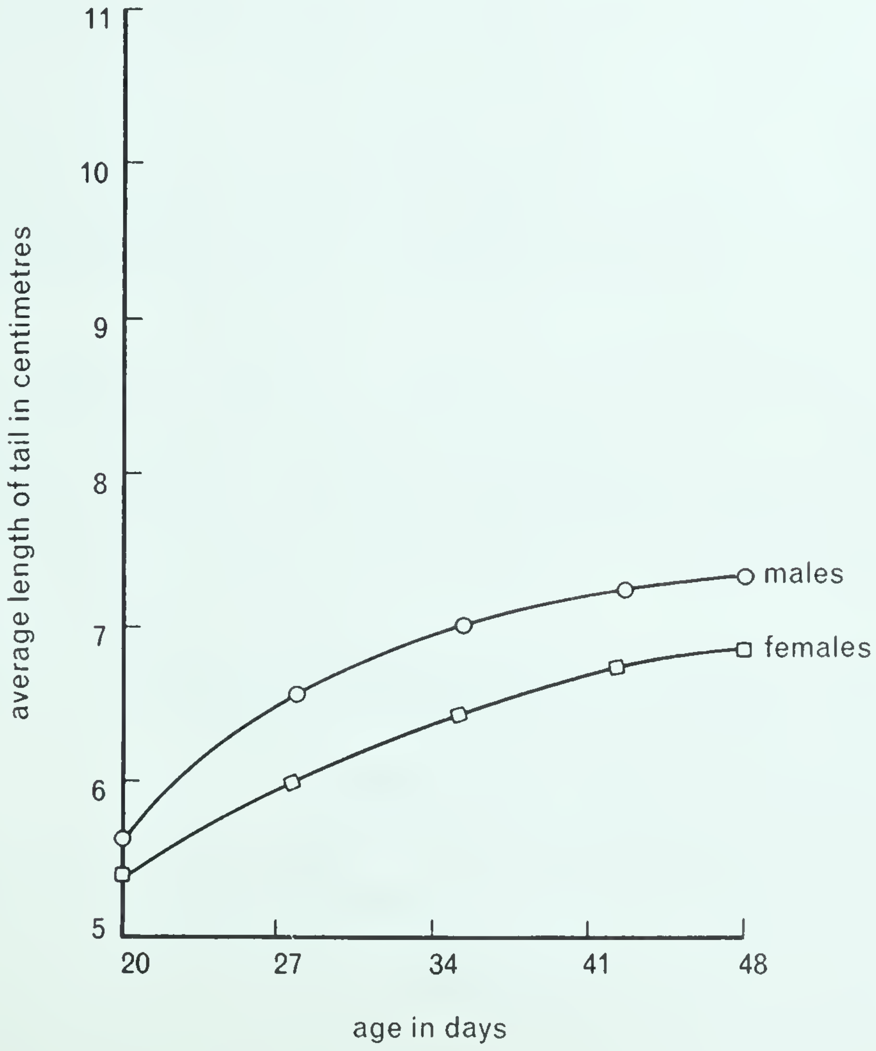


Figure 87
Graph to show the increase in length of the tails of male and female mice.

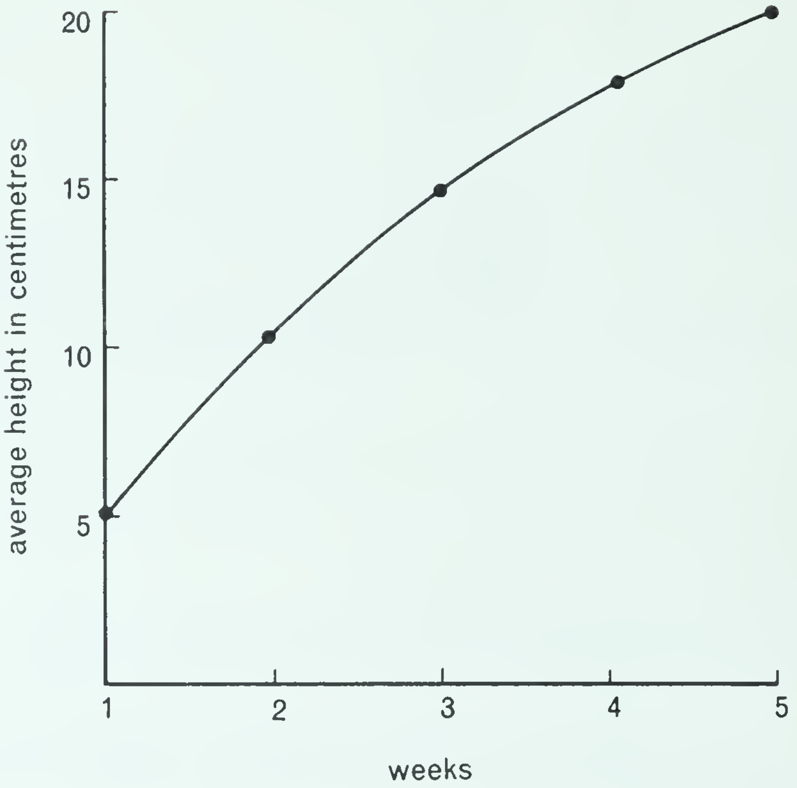


Figure 88
Graph to show the increase in height of wheat seedlings.

b. Did the female mice increase in weight (grow) at the same rate as the males?
c. Were they still increasing in weight at the end of the four weeks?
d. Can you detect any connection between the increase in the length of the tails of the mice and the increase in their weight?
e. Do you notice anything different about the curve you obtained for the increase in length of the wheat seedlings?

By answering these questions you may have thought of some hypotheses. For instance we might say that from our results there seems to be a direct connection between the increase in weight of the mice and the increase in length of their tails. This would be one hypothesis. Can you think of any others? How would you test your hypothesis?

9.15 Is there a relationship between the amount of food eaten and the rate of growth of mice?

Look at your table of results again.

1. On the graph you made in section 9.14 to show the increase in weight of the male and female mice, plot the curve of the average weight of food eaten by one male mouse in a week.
2. Using a different colour, plot the curve of the average weight of food eaten by one female mouse in a week.
3. Compare these two curves with the curves on the same graph showing the increase in weight of the mice.

Did the weight of the mice increase at the same rate as the weight of food they ate? Was this true for both the males and the females?

Can you think of anything else besides the amount of food, which might influence the rate of growth of the mice?

9.2 Telling the ages of animals

From the growth curves you drew of mice in section 9.14 you probably were able to tell that when the mice were about forty-eight days old they did not get any heavier. In other words, they stopped growing and we might say that they were grown up.

In the same way we could make a growth curve for ourselves but this would take a long time since we grow up so much more slowly. Figures 89 and 90 show two growth curves for human beings, in which measurements of growth have been made showing increase in weight (figure 89) and increase in height (figure 90). The curves are different for boys and girls. How do these compare with male and female mice? Look at these curves and see if you can tell at what age humans are grown up. At which ages did (*a*) the boys, and (*b*) the girls grow more rapidly?

If we do not draw growth curves, it is difficult to tell exactly when animals (or plants) are fully grown. But in some animals there may be other ways in which we can tell how old they are. In fish with scales like the herring, for instance, we can tell the age of the fish by looking at one of its scales which have rings on them. Tiny scales first appear on young fish when they are about an inch long. The scales grow larger as the fish grows. In spring and summer when food is plentiful the herring grows more rapidly and the scales grow faster as well. In winter when food is scarce, the scales

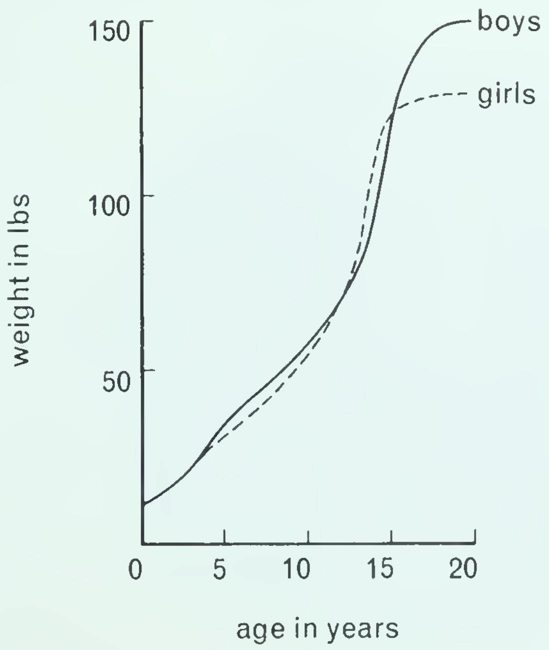


Figure 89
Graph to show the increase in weight of boys and girls.
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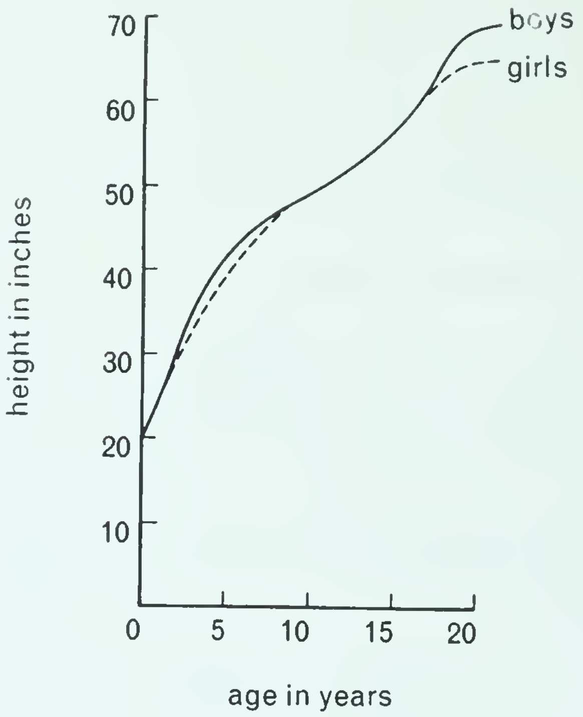

Figure 90
Graph to show the increase in height of boys and girls.
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stop growing and this shows as a ring on the scale which marks the end of that year's growth. Thus by counting the rings on the scales we can tell the age of the herring. How old is the fish from which the scale in figure 91 is drawn?

Are there any ways in which we can tell the age of a plant such as a tree?

9.21 Telling the age of trees

If we look at a tree in winter which has lost its leaves, we can see that at the end of each twig there is a bud which, because of its position, is called the *terminal bud*. In spring this bud bursts and the scales which were covering the bud drop off, each scale leaving a scar. These scars form a ring round the twig and are called *girdle*

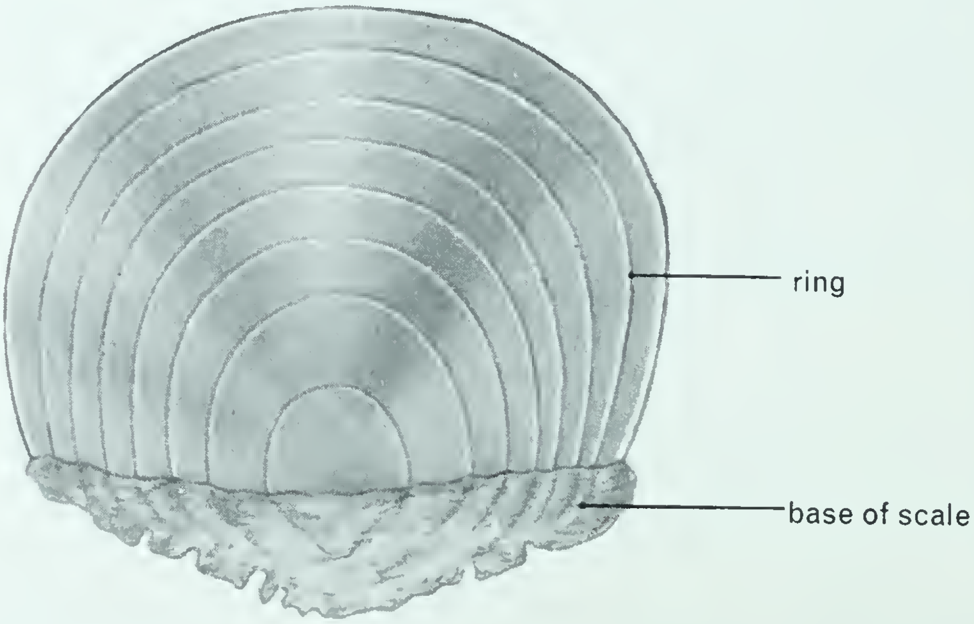

Figure 91
The scale of a herring (greatly magnified).

scars. They mark the position of the terminal bud before it burst and started to grow. Thus each girdle scar marks the end of one year's growth. Figure 92 shows a horse-chestnut twig with girdle scars at intervals up the twig. How old is this twig?

In summer when the leaves are out, it is not so easy to find the girdle scars but you might try looking for them on twigs of any common trees such as the horse-chestnut, beech, or lime.

Examine the twigs provided and see if you can tell their ages. What does the distance between the girdle scars tell you about the rate of growth of the different trees in different years?

You may have found that twigs of the same length but from different trees show different numbers of girdle scars. Thus, for example, a twig of ash may have a girdle scar at the end of every two feet of twig, while a twig of beech or oak of the same length as the ash, may have as many as six girdle scars.

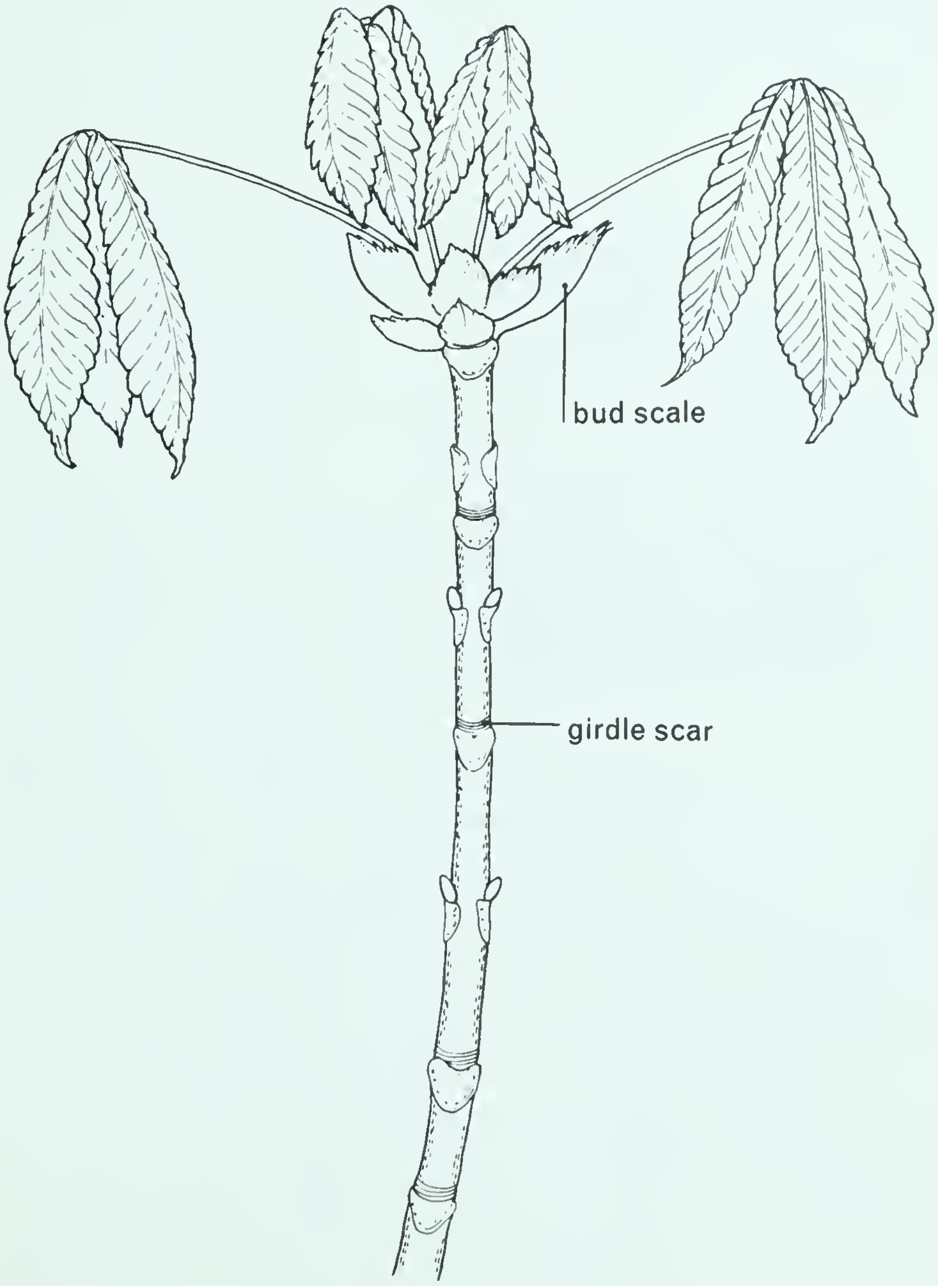

Figure 92
A horse-chestnut twig showing the girdle scars.

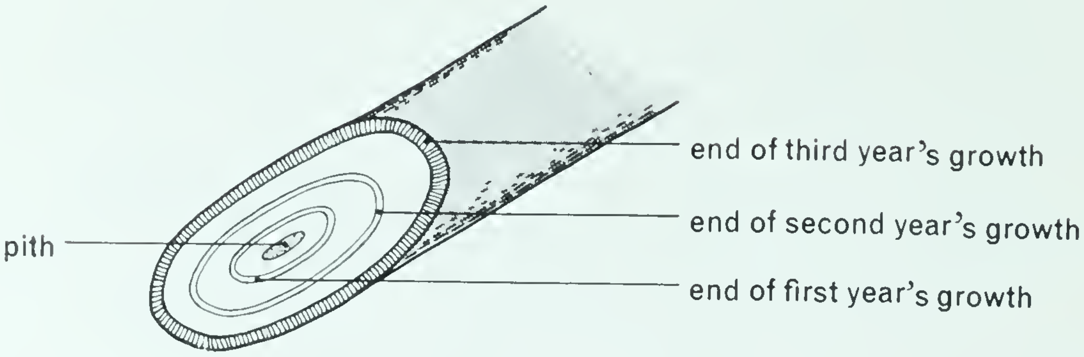
end of third year's growth
end of second year's growth
pith
end of first year's growth

Figure 93
A branch of horse-chestnut cut obliquely across.

There is another way in which we could tell the age of a twig, for, besides growing longer each year, the twig also grows in girth. In spring and summer when a tree is growing fast, a great deal of wood is made, but in the autumn, when the tree loses its leaves, growth slows down and a ring of hard wood is formed rather like the rings on the herring scale. Figure 93 shows a twig three years old cut obliquely across. The rings of harder wood mark the end of each year of growth.

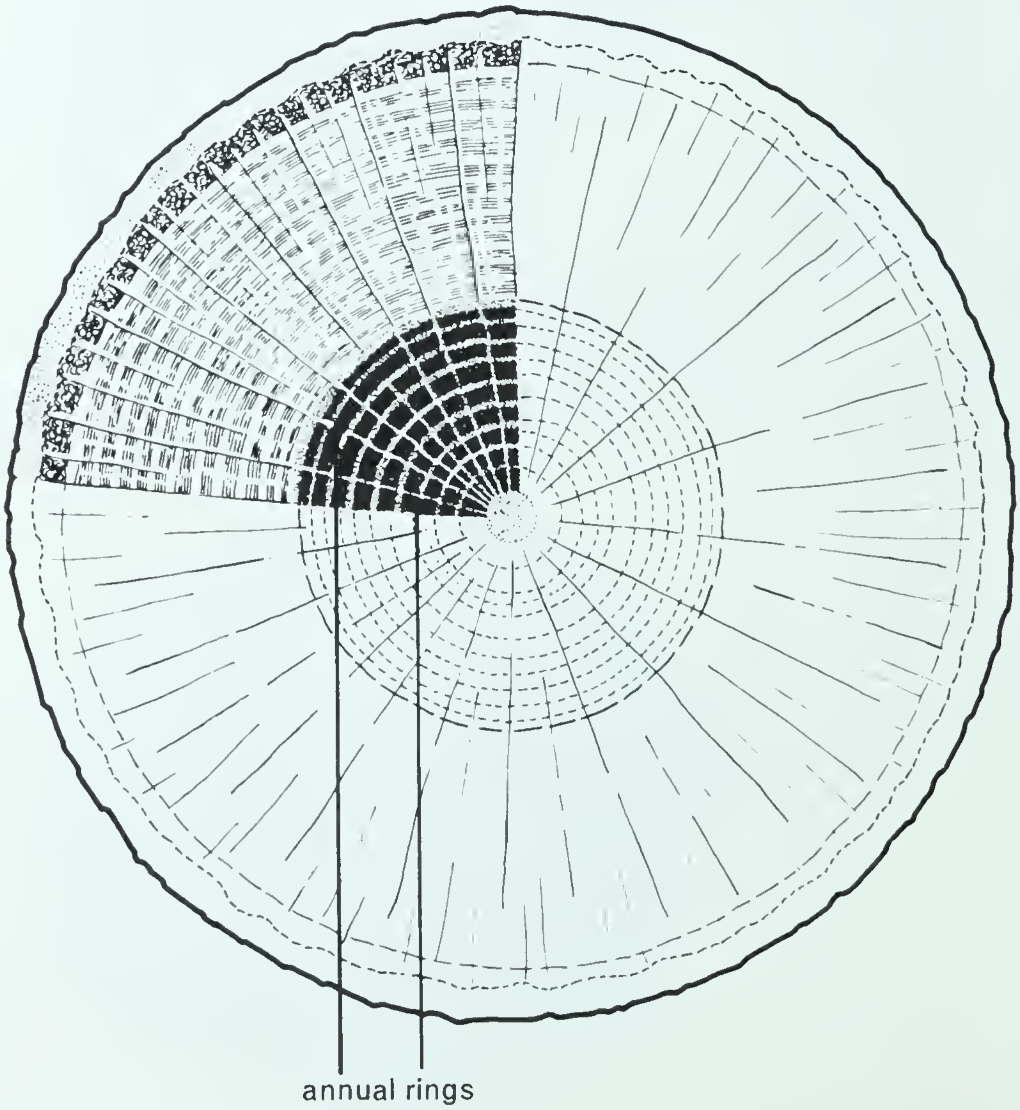

Figure 94
The stump of a tree felled when it was twenty-two years old.

Using one of the twigs on which you counted the girdle scars, cut it obliquely across near the bottom with a penknife. See if you can make out its age.

We can use the same method for estimating the age of a tree, but, of course, to do this we would have to cut the tree down. Instead, we can examine the stump of a tree already felled. Figure 94 shows the stump of a tree which was about twenty-two years old when it was sawn down.

Find the stump of a tree which has been felled fairly recently, and see if you can discover the age of the tree when it was cut down. If you cannot find a tree stump, try a log instead.

9.3 Patterns of growth

If you look again at the drawing of the herring scale in figure 91 you will notice that the rings get closer together towards the outside of the scale. These were the rings most recently laid down and since each ring corresponds to one year of the herring's life we can tell from the scale not only how old the fish was but that the rate of growth of the fish slowed down as it got older.

In trees this is also the case because the annual rings get closer together towards the outside of the trunk.

By looking once more at the growth curves you drew of the mice you will probably see that the young mice did not grow at the same rate during the period in which you made measurements of their weight. During the first two or three weeks they increased in weight more rapidly than during the last two weeks before they were fully grown. The same is also true of man as you can see from the growth curves in figures 89 and 90. These curves show that growth is most rapid between birth and four years and again between eleven and fourteen. It is interesting to compare the growth of boys and girls. On average, girls between eleven and fifteen are heavier than boys but, by the time they are grown up, the average man is both heavier and taller than the average woman.

The question also arises as to whether all the parts of the body grow at the same rate. This is certainly not true of man. If we make a series of drawings of a human being from birth to the time he is grown up so that all the drawings are of equal height, we shall see that the proportions of the body change. At birth the head and legs each account for a quarter of the total height, while in the adult the head is only one-eighth of the total height while the legs have increased to half this height (see figure 95).

We can say, therefore, that in most animals growth is greatest during the first part of their lives and gradually decreases until it finally stops when they are grown up. But does growth stop altogether? In ourselves there are certain parts of our bodies which go on growing throughout our lives – nails and hair, for instance. Some animals, such as frogs and toads, change so much while

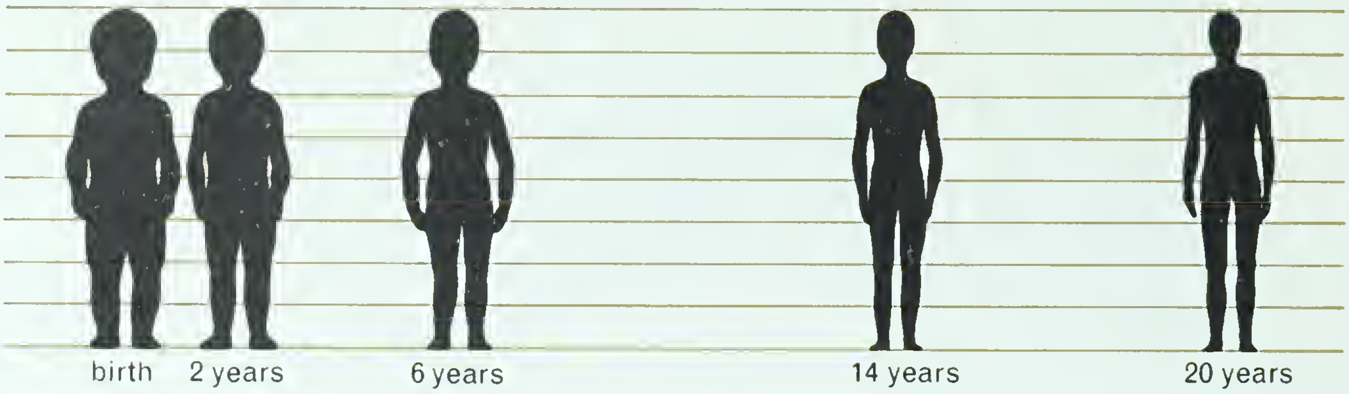

Figure 95
Changes in the proportions of the human body during growth.
Reproduced by permission of BBC publications.

they grow that they pass through distinct stages from tadpoles to adults. In crustaceans and insects which have a hard outer skeleton, growing larger means that a new skeleton must grow underneath the old one which splits at intervals to allow for growth. This is the case in locusts which pass through five nymphal instars. Each time moulting occurs, the skin splits and a larger nymph emerges.

By observing the growth of living things we can see that each kind of animal and plant has its own pattern of growth throughout its life. Not only this, but the different parts of the body grow at different rates.

9.31 The span of life

We have been studying growth and in this chapter we have been particularly concerned with growing up and how long it takes to reach adult size. This leads to the question of how long different animals and plants go on living after they have grown up.

We know that the average life span of man is about seventy years but that a few people live to be over 100. The Indian elephant has also been known to live to 100 years although, like man, its average span of life is seventy. At the other end of the scale there are some insects, such as mayflies, which live for only a day.

Figure 96 shows the average life span of some animals in the form of a clock. In the case of wild animals it is often impossible to judge the average length of life because they tend to die younger than they would in captivity. Tree frogs have been known to live in captivity for as long as six or seven years, whereas under natural conditions most die within two years. The clock in figure 96 shows the life spans of wild animals compiled from records kept by zoos.

On the whole, it is probable that animals which spend a lot of their lives in winter sleep (hibernation), such as bats, tend to live longer than animals of similar size which are active all the year round – mice and shrews, for instance.

Sometimes animals manage to achieve ages far beyond their average span of life. Below is a list of some of the most long lived individuals from a number of different species.

From this list you can see that apart from the giant tortoise, which spends a great part of the year sleeping and is a slow-moving animal anyway, only man and the Indian elephant are known to be able to live for 100 years.

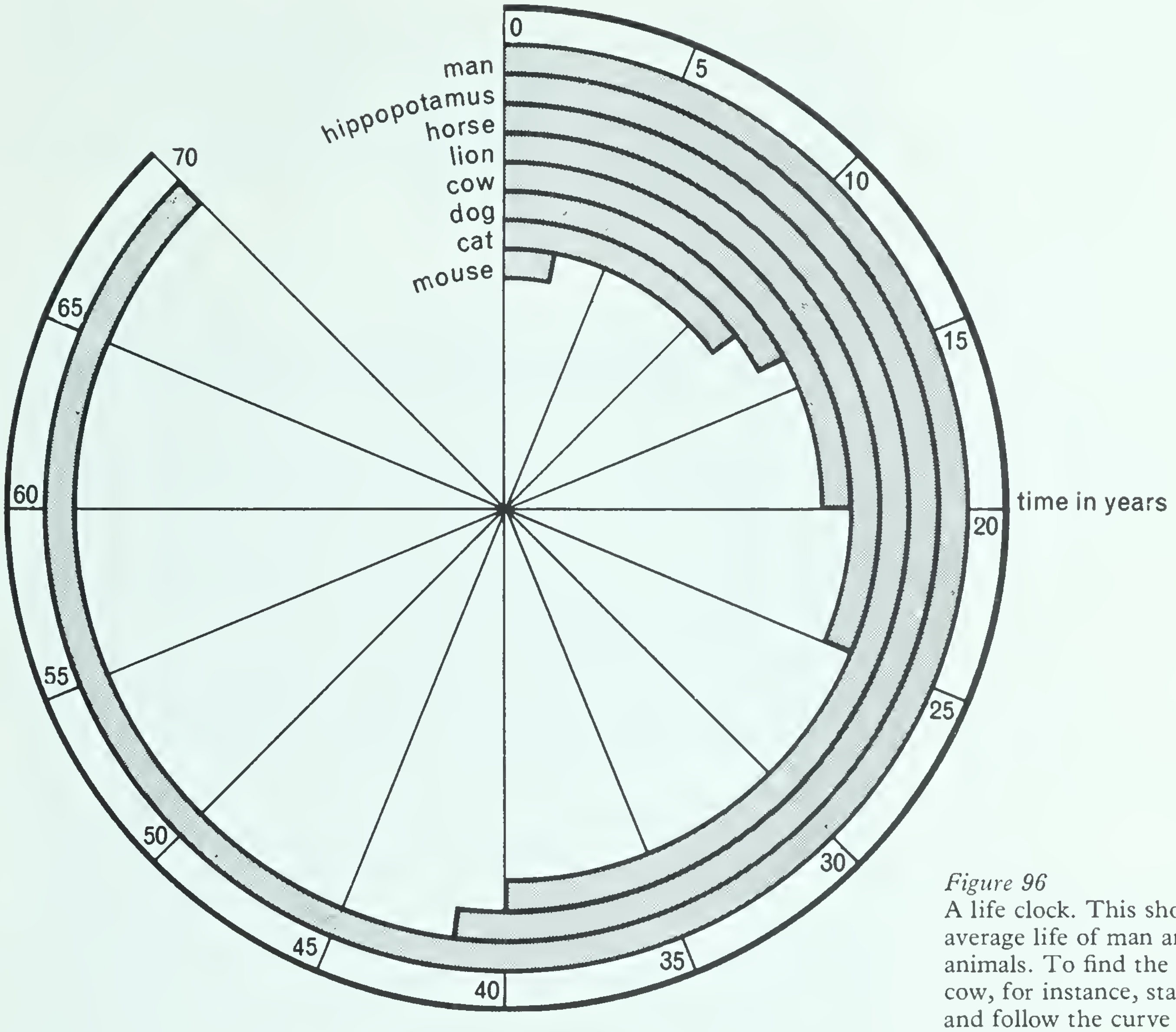

Figure 96
A life clock. This shows the average life of man and various animals. To find the life span of a cow, for instance, start at 0 years and follow the curve round until it ends. Then read the number on the clock face.

	Possible great ages attained
Man	120 years
Indian elephant	100 years
Whale	50 years
Camel	40 years
Cat	33 years
Chimpanzee and orang-outang	30 years
Parrot	60 years
Giant tortoise	over 200 years
Slow worm	54 years
Boa constrictor	23 years
Carp	80 years
Salmon	25 years

Among plants some of our common weeds such as groundsel and shepherd's purse live only for a few weeks while many trees live to a great age. Yews, cedars, and plane trees can live to over 1,000 years, and the giant Californian redwoods to over 4,000 years. Indeed the life span of the Californian redwood or *Sequoia* is greater than any other living thing.

Summary

Growth in animals and plants takes place in several ways such as increase in length or height, in girth, or in weight. It can be measured by various methods. By plotting growth curves from these measurements we can discover whether growth goes on at the same rate all the time. Each kind of animal or plant grows only to a certain size, so that we can also tell from growth curves at what age growth in size ceases. We can also see that there is a pattern of growth, increase in size being usually greatest at the beginning of the growing period.

The life span of animals and plants varies greatly. In animals it ranges from a few days to over a hundred years while there is one kind of tree which may live for as long as 4,000 years.

Man and his environment

By now you will have investigated a number of different animals and plants and found out how they reproduce and how their young develop and grow up. You will realize that in order to grow up successfully a plant or animal must live in the right sort of place. An earthworm, for instance, is the right shape to live in the soil. Its body is constructed in such a way that it can move easily through the soil and feed on the plentiful supply of decaying vegetable matter which occurs there as humus. But if we dig up an earthworm and put it on a sheet of glass, it can neither move freely nor escape from its enemies. If we were to place food in front of it on the glass, the worm would probably be unable to reach it. The soil, therefore, is the earthworm's natural environment or what is often called its *habitat*.

All animals and plants have their particular habitats where they can live successfully and multiply. Some voles, for instance, live in holes in a bank. There they make their nests and rear their young close to their supply of food – insect larvae and wild fruits. Similarly, plants can live only in certain habitats – ferns and mosses require damp places, while species such as ivy prefer a wall or a tree trunk to climb up as they grow.

We must not forget that living things are themselves part of a habitat. One animal or plant may be dependent upon another for its food and even to assist in its reproduction. This is the case in many flowers which, as we have seen, depend upon insects of different kinds to transfer pollen from one flower to fertilize another.

The great naturalist Charles Darwin, who lived over one hundred years ago, discovered that red clover could only be pollinated by bumble bees. Because they have longer tongues than some insects, bumble bees can reach the nectar at the bottom of the flowers upon which they feed. In a field of clover, bank voles often destroy the grass nests and larvae of the bumble bee, and then use the nests in which to rear their own young. The voles are, in turn, eaten by birds of prey such as the owl, which fly over the field. Thus in a single field habitat, there is a community of plants and animals each depending upon the other for its supply of food.

We can summarize the situation as:

Red clover → bumble bees → bank voles → owls

Each separate source of food is like a link in a chain – often known as a *food chain*. What sort of organism would we expect to find at the right hand end of the chain?

So long as the numbers of plants or animals at each link of the chain do not increase or decrease too much, the population of a habitat can go on living continuously as a *balanced community*.

But what happens if this balance should be upset by altering one or more of the links in the chain? Suppose a gamekeeper kills off all the owls and other birds of prey in the area. The enemies of the bank vole will then be reduced and the voles can multiply unhindered. With so many to feed, their food will become scarce and the voles will attack and destroy more nests of bumble bees, eating their larvae. This, in turn, will mean that fewer clover flowers will be pollinated and fewer seeds produced. Soon there will be no clover in the field, and the community will cease to exist.

Thus, by destroying owls, man can upset the balance in a field habitat. But he can do this in other ways as well. By spraying plants with insecticides like DDT, for instance, he may kill not only insect pests such as aphids, but also the bumble bees and other useful insects visiting for nectar the flowers of the plants which have been sprayed.

Besides the use of harmful sprays, man can upset the balance of a community by other means. Many of our rivers are now heavily polluted with chemical waste from factories and even with sewage from town drains. This means that the fish in the rivers may be killed and that, in turn, the water fowl and other birds which feed on the fish may die either of starvation or poisoning.

In the last chapter we considered what happens when we grow up. We have seen how growing up means not only getting larger, but also using our senses and our brains to become more aware of the things around us. In this, man differs from all other animals. Not only does he have a memory but he is also able to think and reason. That is to say he is able to plan what he is going to do in the light of his experience, before he actually does it. Before we spray our roadside plants, or turn sewage into our rivers, or take birds' eggs, we should pause to think what the results of our actions are likely to be. In other words, we must develop and use our ability to reason because, in the long run, we are the people who will bear responsibility for the destruction or the preservation of the places in which we live. The countryside, as well as being a source of food, is also there for our enjoyment, and as we grow up we should become aware of how we can all be an influence for good (or bad) in its preservation.

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Keys to small organisms in soil, litter, and water troughs

Film Loop notes